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THESIS

AN ANALYSIS OF LOGISTICS RESPONSE TIMES FOR REQUISITIONS OF NAVAL AVIATION REPAIRABLE ITEMS

by

Gregory L. Booth

June 2002

Thesis Advisor: Robert A. Koyak
Second Reader: Kevin J. Maher

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Minimized safety level investment, while achieving high service levels and low customer wait time, is critical to the performance of the United States Navy supply system. The Naval Inventory Control Point (NAVICP) uses the Uniform Inventory Control Program to compute safety levels for each of the stock items they maintain. To assist in computing these levels, NAVICP aggregates repairable items based on demand and cost. The performance metrics used to measure the effectiveness of the model, Supply Material Availability and Average Days Delay, are affected by this aggregation. The purpose of the thesis is to describe an alternative methodology of aggregation that will allow NAVICP to allocate its item management skills more efficiently.

The proposed methodology, based on item cost, demand, and Logistics Response Times for requisitions, can improve inventory performance without increasing the workload of item managers. Using analysis of variance, an analytical approach is adopted to ascertain whether an item has an average Logistics Response Time that exceeds the Navy's goal. It is shown that the proposed aggregation can improve Supply Material Availability and safety level investments while better managing items based on Logistics Response Time.

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Gregory L. Booth
LCDR, SC, USN
B.A., Virginia Military Institute, 1991

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June 2002

Author: Gregory L. Booth

Approved by: Robert A. Koyak, Thesis Advisor

Kevin J. Maher, Second Reader

James Eagle, Chairman
Department of Operations Research

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ABSTRACT

Minimized safety level investment, while achieving high service levels and low customer wait time, is critical to the performance of the United States Navy supply system. The Naval Inventory Control Point (NAVICP) uses the Uniform Inventory Control Program to compute safety levels for each of the stock items they maintain. To assist in computing these levels, NAVICP aggregates repairable items based on demand and cost. The performance metrics used to measure the effectiveness of the model, Supply Material Availability and Average Days Delay, are affected by this aggregation. The purpose of the thesis is to describe an alternative methodology of aggregation that will allow NAVICP to allocate its item management skills more efficiently.

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LIST OF ACRONYMS

ADD	Average Days Delay
ADDR	Average Days Delay for Delayed Requisitions
ALT	Administrative Leadtime
ANOVA	Analysis of Variance
CARES	Computation and Research Evaluation System
DAASC	Defense Automatic Addressing System Center
DDD	Defense Distribution Depot
DLA	Defense Logistics Agency
DOD	Department of Defense
DTO	Direct Turn Over
FFR	Fleet Freight Routing
FISC	Fleet and Industrial Supply Center
FY	Fiscal Year
ICPRT	Inventory Control Point Response Time
IPG	Issue Priority Group
LMARS/CWT	Logistics Metrics Analysis Reporting System/Customer Wait Time
LSSI	Levels Setting Segment Indicator
MALS	Marine Aviation Logistics Squadron
MDF	Master Data File
MRO	Material Release Order
MSE	Mean Square Error
NAVICP	Naval Inventory Control Point
NAVSUP	Naval Supply Systems Command
NIIN	National Item Identification Number
NRFI	Not Ready for Issue
LRT	Logistics Response Time
PDLT	Production Leadtime
QQ	Quantile-Quantile

RTAT	Repair Turn Around Time
SMA	Supply Material Availability
TVC	Total Variable Cost
UIC	Unit Identification Code
UICP	Uniform Inventory Control Program

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I cannot forget the real motivation behind completing this "rat" on time - my family. There was no way I was going to extend this thing. There were many late nights in the Booth household. Ann-Marie, Tyler, Ryan, Abby and Paul, thanks for keeping me on track.

"Forgetting what is behind and straining toward what is ahead, I press on toward the goal to win the prize for which God has called me heavenward in Christ Jesus."
Philippians 4:13-14

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EXECUTIVE SUMMARY

The Naval Inventory Control Point (NAVICP) uses several performance metrics to measure the effectiveness of its inventory models. Supply Material Availability (SMA) measures the quantity of material that is on hand for immediate issue. Average Days Delay (ADD) and Average Days Delay for Delayed Requisitions (ADDR) measure how long it takes the NAVICP to release the material for shipment to the customer. The goal of NAVICP is to maximize SMA while minimizing ADD and ADDR, within budgetary constraints. The purpose of this endeavor is to ensure that the ships and aircraft of the Untied States Navy receive the parts that they need on time and as fast as possible.

NAVICP attempts to achieve its goal by aggregating its inventory by cost and demand for more effective management. There are 44 total "segment" cells, comprised of eleven cost categories crossed with four demand categories. The four demand categories are further segmented between "focus pool" and "non-focus pool" stock items. Focus pool stock items receive the greatest managerial attention. The goal of segmentation is to group stock items with similar attributes in order to manage them more effectively.

In addition to SMA, ADD, and ADDR, a metric of increasing importance to NAVICP is Logistics Response Time (LRT). Although ADD and ADDR are important components of LRT, the latter also includes processing and shipping time of requisitions, which are not reflected in the former metrics. Shipping time varies widely due to the priority of the requisition; to its immediate issue or backorder; to its origination from a shore versus a fleet activity; and to its designation for stock or for maintenance. The Navy has adopted the goal of achieving an average LRT of twenty-five days for all items, and an average of fourteen days by fiscal year 2005.

The purpose of this thesis is to develop a more effective segmentation of the Navy's inventory items by including LRT as an additional segmentation criterion. Unlike cost or demand, the average LRT of an item is inferred from an analysis of requisition data. These averages are subject to sampling variability due to the small

sample sizes for many of the items, and to the dependence of LRT on characteristics of the requisitions. The requisition priority, issue type, requisition type, and service designation (location) of the customer each have a significant effect on LRT. By accounting for these effects using analysis of variance techniques, it is possible to describe more precisely the effect that the item itself has on LRT. This analysis allows LRT to be incorporated into item segmentation in a manner that better reflects the efficiency goals of the Navy.

Requisition data for fiscal year 2001 encompassing nearly one-quarter million records, and nearly eight thousand inventory items, were analyzed for the thesis research. An outcome of this analysis is the identification of items in the non-focus pool that had both lower SMA and higher average LRT that require additional management attention. NAVICP can allocate its fixed managerial assets more effectively by periodically identifying non-focus pool items with low SMA and high LRT and placing them in a "focus" group. This refining also identifies focus pool items achieving SMA and LRT goals.

I. INTRODUCTION

The United States Navy requires a robust system to supply parts that are used in maintenance on ships and aircraft, in order to support the many contingency operations that the Navy is called upon to undertake. The Naval Inventory Control Point (NAVICP) has the task of ensuring that there is inventory on hand to meet the demands of the operational forces. NAVICP manages its spare parts inventory by segmenting the inventory into "cells" that have similar cost and demand to achieve overall material availability goals. The problem with this segmentation is that high-cost items are not meeting established availability goals. As a result, customer wait times for these high-cost items are also failing to meet established customer wait time goals. Aircraft and ships cannot achieve their operational readiness goals due to long customer wait times. The existing segmentation methodology using cost and demand is a cause of this inflated wait time and lower material availability (Ropiak, 2001).

This thesis investigates an alternative method for segmentation, which introduces Logistics Response Time (LRT) as an additional criterion. LRT is the customer wait time discussed above and is further defined in section A of this chapter. Analysis of variance (ANOVA) techniques are used to ascertain the sources of variability in mean LRT for aviation repairables. ANOVA produces the statistics necessary to classify the items using confidence bounds as having either "High LRT", "Low LRT", or "Indeterminate". This classification is based on the Navy's Fiscal Year (FY) 2005 mean LRT goal of 14 days (Evans, 2001)[1]. At the time this thesis was written, the Navy's mean LRT goal was 25 days across all NIINs. Of the 7,902 NAVICP aviation repairables this thesis researches, nearly 40 percent have mean LRT greater than the Navy's FY 2002 goal; over 60 percent have mean LRT greater that the Navy's FY 2005 goal.

[1] The reason behind using 14 days vice 25 days as the goal is discussed in Chapter V.

A. BACKGROUND

NAVICP manages inventory levels for over 436,000 National Item Identification Numbers (NIIN)[2], valued at over $34.5 billion in FY 2002 from two sites, Mechanicsburg and Philadelphia. NAVICP-Mechanicsburg is responsible for spare parts used on Navy surface ships and submarines. NAVICP-Philadelphia is responsible for the purchase of approximately 154,000 Naval aviation NIINs valued at over $27.5 billion in FY 2002 (Klaczak, 2002). Spare parts are classified as either consumable or repairable. Consumable items are relatively low-cost items that are discarded when they fail. By contrast, a repairable item is usually high-cost and can be serviced when it fails and then reused. This thesis will focus on aviation repairables managed by NAVICP-Philadelphia. The term NAVICP is used to represent the Philadelphia site in the remainder of this thesis.

The United States Navy commits substantial resources annually to the repair and procurement of these needed parts to support fleet operations. NAVICP, which is under the command of the Naval Supply Systems Command (NAVSUP), has two primary responsibilities in this investment. The first is to ensure that parts are ready for issue when ships, squadrons and aviation depots order them. The second is to maintain inventory levels at the minimum levels needed to ensure operational effectiveness of the Navy. The purpose of setting safety levels for inventoried parts is to balance these two conflicting objectives. If demand for a particular item does not exceed the forecast demand, the safety stock sits on the storeroom shelf. This buffer of unused material is a cushion to meet unforeseen spikes in demand during leadtime. However, the resources needed to maintain this buffer could have been used elsewhere to support Navy operations. On the other hand, if demand exceeds its forecast, the safety level is used to fill those unanticipated demands, thereby justifying the investment.

Aviation repairables are segregated in a number of ways to improve inventory management. To this end, NAVICP segregates repairables into a “focus pool” and a “non-focus pool”. Focus pool items are those designated by NAVICP to be of special

[2] A National Item Identification Number (NIIN) uniquely identifies each repairable managed by NAVICP. The terms “line item”, “spare part”, and “stocked item” are synonymous to NIIN and are used throughout this thesis.

interest due to their mission essentiality. Approximately 80 percent of requisitions made to NAVICP are for items in the focus pool. To facilitate the computation of safety levels, NAVICP further segregates items into a matrix based on two criteria, cost[3] and demand. Each criterion is further divided into eleven cost categories and four demand categories. This matrix, called the Levels Setting Segment Indicator (LSSI) matrix, contains 44 cells. Each cell within the LSSI matrix is assigned a shortage cost, which is used to compute safety levels for each item within that cell. The LSSI matrix will be discussed in further detail in Chapter II.

The shortage cost is the imputed "opportunity cost" that NAVICP would pay for a stock out. Shortage costs, and therefore safety levels, vary across items. High-cost items require greater costs to maintain conservative safety levels, while ensuring the operational capability of Naval aircraft weapon systems. Similarly, if an item were essential for the operation of a weapon system, the cost of a stock out would be high, thus a need results requiring a higher safety level.

The Navy supply system uses Supply Material Availability (SMA) as its primary performance metric. SMA is defined as the percentage of time that material is available for immediate issue. Safety levels of inventory items are set to ensure that SMA remains acceptably high across all items while minimizing the investment in safety stock. The SMA for each NIIN within each LSSI cell varies, as does the average SMA within the cells of the LSSI matrix. The overall SMA goal mandated by NAVSUP is 85 percent.

Logistics Response Time, which is the elapsed time from when an end-user orders a part to when it is received, is a performance measure of increasing interest to the Navy. Figure 1.1 shows boxplots of Base-10 logarithm of LRT[4] for each LSSI cost category. These cost categories range sequentially from lowest cost ("A") to highest cost ("K"). It is apparent from Figure 1.1 that the medians of mean log (LRT) within each category increase as the cost increases. Figure 1.1 suggests that the performance metrics of high cost items are not meeting the FY 2005 goals set by NAVICP[5]. One problem NAVICP faces is how to improve SMA and LRT with limited financial resources. The relative

[3] This cost is actually a weighted cost and is discussed in Chapter II. The terms "cost" and "weighted cost" are used interchangeably when used in discussion of the LSSI segmentation criterion.
[4] Due to the nature of the data, base-10 logarithms of LRT are used to graphically illustrate this metric in this thesis. However, the natural logarithm is used in the analysis of variance discussed in Chapter V.
[5] For comparison, the base-10 logarithm of 14 days is 1.14.

importance of LRT and SMA as performance metrics continues to be an item of discussion among inventory analysts.

LRT consists of twelve measurable components; this thesis investigates two of those components, inventory control point response time (ICPRT) and process and shipping time. The ICPRT measures how long it takes NAVICP to release the item from its inventory using a material release order (MRO). ICPRT depends on the availability of an item (SMA) and its processing time. The process and shipping time is the time from the stock point issue to the end-user receipt. Both of these times can be managed to improve LRT of a particular item's requisitions.

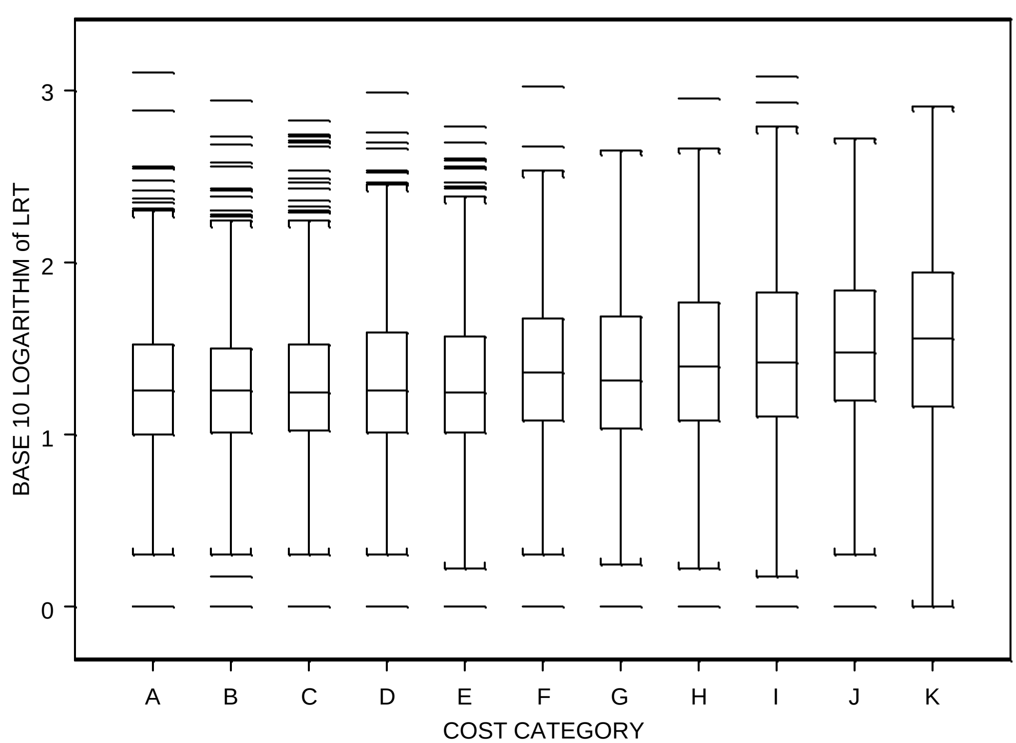

Figure 1.1: Boxplots for Base-10 Logarithm of Logistics Response Time (LRT) by LSSI Cost Category, FY 2002. The boxes encompass values from the twenty-fifth through the seventy-fifth percentiles. Lines inside the boxes indicate the medians. The eleven cost categories are ordered from "A " (lowest) to "K" (highest).

B. BUDGET IMPACT

NAVSUP provides NAVICP funding authority to purchase and repair items in order to maintain adequate wholesale inventory levels. These wholesale inventory levels support retail inventory requirements and fill end-user requirements for items not-carried or not-in-stock in the retail inventory. Retail inventories are those items located close to the end-user for immediate issue when needed. These include ships, aircraft squadrons or repair facilities, which will use the item either to repair or replace aircraft components. In FY 2002 NAVSUP allocated funding of $4.0 billion to support its two ICP activities in Mechanicsburg and Philadelphia. NAVICP received $3.3 billion to procure and repair aviation items (Finley, 2002). This funding is used to maintain wholesale inventory levels to meet the 85 percent overall SMA goal established by NAVSUP.

Due to funding constraints, there is an additional problem with the existing LSSI management concept. The inventory model using the existing LSSI matrix results in funding allocations that ensure that low-cost items are funded to achieve higher SMA. This offsets the lower SMA of high-cost items. This results in stocking higher levels of "cheap" items to achieve the 85 percent overall SMA goal (Ropiak, 2001). Figure 1.2 displays boxplots of SMA for each cost category under the LSSI segmentation that was in effect in FY 2002. It is apparent that the median SMA decreases as the cost increases. As a result of this funding allocation, end-users are subjected to longer waiting times for high-cost items because those items experience lower SMA.

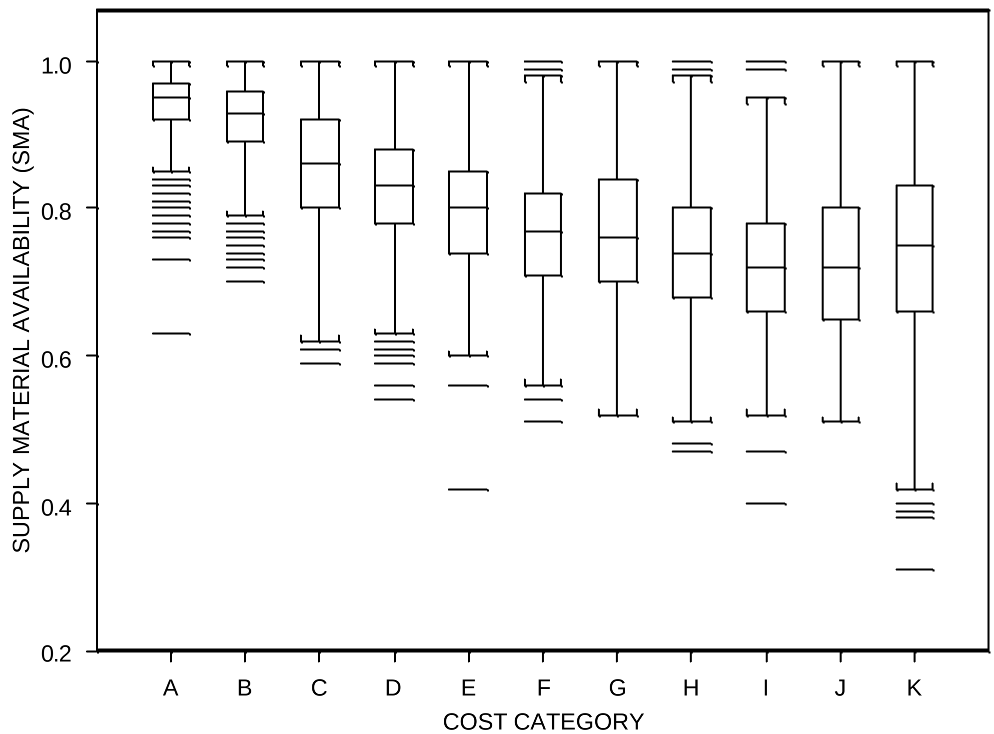

Figure 1.2: Boxplots for Supply Material Availability (SMA) by LSSI Cost Category, FY 2002. The boxes encompass values from the twenty-fifth through the seventy-fifth percentiles. Lines inside the boxes indicate the medians. The eleven cost categories are ordered from "A " (lowest) to "K" (highest).

C. THESIS OBJECTIVES

The objective of this thesis is to prescribe a methodology to reconfigure segmentation of Navy aviation repairable items. This methodology incorporates LRT along with cost and demand to modify the segmentation currently represented by the LSSI matrix. This is done by characterizing each NIIN by its mean LRT, accounting for variability of factors that influence LRT, which are specific to individual requisitions. These factors include service designator, issue type (e.g. backordered or not), requisition type, priority, and the NIIN itself as predictor variables. This thesis formulates analysis of variance models. From these models, confidence bounds are calculated and are used to classify the item with high confidence in one of three categories, "High LRT", "Low

LRT", or "Indeterminate". In addition to this new segmentation criterion, the cost criterion of the existing LSSI matrix is reduced from 11 categories to six. The existing LSSI demand criterion is not changed. The proposed LSSI matrix contains 48 cells "segmented" by four demand categories, six cost categories and two LRT categories.

The effectiveness of the proposed segmentation is measured in two ways. First, non-focus pool items exhibiting "bad" performance, i.e., high LRT and low SMA, are identified through the use of the proposed matrix. In addition, those focus pool items exhibiting "good" performance, i.e., low LRT and high SMA, are identified through the use of the proposed matrix. The "bad" items are brought into the "focus" of item managers based on management direction. An equal or greater amount of "good" items are taken away from the "focus" of item managers based on management direction.

The second measure of effectiveness is to compute and compare the aggregate safety levels for all researched items in the existing and proposed LSSI matrices. In addition, an item-by-item comparison of projected SMA and safety level is conducted.

D. ORGANIZATION OF THE THESIS

The remainder of this thesis is organized as follows. Chapter II briefly discusses the Naval aviation supply system; it also discusses the Levels Setting Segment Indicator matrix and how its shortage costs are used to compute safety levels. Chapter III presents the requisition process as it relates to LRT starting with the requirement determination and ending with the customer receipt. Causes of high LRT are identified. Chapter IV describes the NAVICP data used in this thesis. Chapter V discusses the models used in the classification of the NIINs, the methodology used in the proposed segmentation, and presents the results of the analysis. Chapter VI presents conclusions and recommendations.

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II. THE NAVAL AVIATION INVENTORY SYSTEM

This chapter presents a brief description of the wholesale inventory system that manages aviation repairables. The wholesale inventory model for consumables is discussed because it is the foundation for NAVICP's repairable model. This "consumable" model uses a variable known as "RISK" to determine safety levels for each item. RISK is a function of demand, cost, requisition frequency and shortage cost. The first three of these parameters are unique to each NIIN; the shortage cost is unique to the individual Levels Setting Segment Indicator cell that a NIIN belongs to. Once the shortage costs are determined for each LSSI cell, the Computation and Research Evaluation System (CARES) analyzer is used. CARES evaluates the safety levels and projects SMA for all items within the cell, compiling a weighted average SMA for each LSSI cell. This chapter discusses the relationships among these components of the aviation inventory system.

The United States Navy maintains wholesale inventory of spare parts to meet its operational needs. Two questions that must be answered in managing this inventory are 1) how much of each item should be purchased (*the order quantity*), and 2) when should orders be placed (*the reorder point*)? There are conflicting objectives that must be taken into consideration when answering these questions:

1. Items must be available when and where they are needed;
2. Inventory levels must be maintained within budgetary limitations;
3. Available storage space must be used effectively.

Retail level refers to stock that is located in close proximity to the customer. LRT is used in the models that compute retail levels. Wholesale inventory is what the Navy uses to replenish the retail inventory levels as well as to fill direct-turn-over (DTO) requisitions for items not carried or not-in-stock in retail inventories.

The Navy uses a series of applications in the Uniform Inventory Control Program (UICP) to compute both retail and wholesale inventory levels. It also forecasts demand, computes projected service levels, and estimates inventory control point response times for both immediate fills and delayed fills due to backorders. A backorder is a requisition

that was unable to be filled when it was received by NAVICP, but will be filled when material becomes available.

A. BASIC INVENTORY THEORY – CONSUMABLES

Detailed derivations of the consumable and repairable models used in UICP are presented in NAVSUP (1993). A general reference on the theory behind these models is Hadley and Whitin (1963). The major assumptions underlying the UICP models are stated below:

1. There exists a continuous review system where the ICP requirements and assets are known at all times.
2. There exists a steady state environment. This implies that mean demand, leadtimes and repair turn around times, although variable, remain constant over time.
3. An order is placed once the reorder level is reached and the entire order is received at the same time. This reorder level is non-negative. The order quantity is constant. There are no budgetary limitations allowing the entire order quantity to be procured.
4. Backorder or shortage costs are known and can be quantified.
5. The military essentiality of the item can be quantified. This factor attempts to quantify the worth of an item to the overall mission in respect to operational availability.
6. Units are demanded one at a time.
7. The cost of an order is constant and is independent of order quantity.
8. Demands are either filled or backordered. There are no lost sales.

The objective of the Navy's inventory system is to minimize total variable costs (TVC) where,

$$\text{TVC} = \text{Average Annual Order Costs} + \text{Average Annual Holding Costs} + \text{Average Backorder Costs.} \quad \textbf{(1)}$$

Backorder costs are also known as shortage costs. In mathematical terms, the final formula used for average annual TVC in UICP is:

$$\text{TVC} = \frac{4DA}{Q} + IC\left(\frac{Q+1}{2} + R - DL + B(Q,R)\right) + \frac{lE}{S}B(Q,R)\,, \qquad \textbf{(2)}$$

where,

D	~	Quarterly demand	R	~	Reorder level
A	~	Order cost	L	~	Leadtime
Q	~	Order quantity	$B(Q,R)$	~	Expected number of backorders
I	~	Holding cost rate	λ	~	Shortage cost
C	~	Unit cost	E	~	Military essentiality factor
S	~	Average requisition size			

To compute the economic order quantity (EOQ or Q*), the partial derivative of (2) with respect to Q is taken and set equal to zero. Based on assumptions described in Maher (1993), EOQ is:

$$Q^* = \sqrt{\frac{8DA}{IC}}\,, \qquad \textbf{(3)}$$

where D is the quarterly demand, A is the order cost and IC is the holding cost. The economic order quantity is then constrained so it cannot exceed six quarters of leadtime demand and must be at least one quarter of leadtime demand.

Computing the reorder point requires several steps. The first is to take the partial derivative of the TVC with respect to R and setting the result equal to zero. This results in the risk formula, which represents the optimal probability of stockout. The final risk equation is

$$\text{RISK} = \frac{DIC}{DIC + lEW}\,, \qquad \textbf{(4)}$$

where W is the average quarterly frequency of demand (NAVSUP, 1993 and Maher, 1993). RISK is constrained based on the level of risk of stockout for an item. The value of RISK in the UICP model is constrained to be between 0.01 and 0.45. Once RISK has been determined the reorder point can be calculated based on the probability distribution of the leadtime demand (Maher, 1993). If the leadtime demand is assumed to

be a normally distributed random variable, the reorder point, R, is calculated to be the mean leadtime demand (DL) plus the safety level ($z\sigma$). In other words,

$$R = DL + z\sigma, \qquad \textbf{(5)}$$

where σ is the standard deviation of demand during leadtime and z is the standard normal deviate associated with the RISK value. If the leadtime distribution is either Poisson or negative binomial, R is the smallest integer that satisfies the following inequality:

$$F(R) \geq 1 - \text{RISK}, \qquad \textbf{(6)}$$

where F(R) is the cumulative probability distribution of leadtime demand evaluated at R.

B. BASIC INVENTORY THEORY –REPAIRABLES

The Navy must incorporate the repair process into the model described in (2). In addition to the order quantity and the reorder point, NAVICP must determine the repair quantity and the repair level. The UICP repair model is composed of two sub-models, one for procurement of new items and the other for repairing not-ready-for issue (NRFI) items, also known as carcasses. Both components of the repair model are constructed in the same manner that the consumable model was developed. Total variable cost for the procurement sub-model is given by the equation:

$$\text{TVC}_{\text{PR}} = \frac{4(D-G)A}{Q} + IC\left(\frac{Q}{2} + R - Z + B_1\right) + \frac{lE}{S}\left(\frac{4(D-G)}{Q}\right)B_1 \qquad \textbf{(7)}$$

where,

G ~ Regeneration rate
D-G ~ Attrition demand
Z ~ Procurement problem variable
B_1 ~ Expected number of backorders at the end of a lead time

The regeneration rate, G, is computed by multiplying the estimated carcass return rate by the forecasted carcass repair survival rate; this product is then multiplied by the forecasted quarterly demand, D, to get the final figure.

The attrition leadtime demand, also known as the procurement problem variable (Z), is computed by multiplying the forecasted quarterly demand by a weighted leadtime, L_2. In other words,

$$Z = DL_2 \qquad \textbf{(8)}$$

where,

$$L_2 = \frac{D-G}{D} L + \frac{G}{D} T_2 , \qquad \textbf{(9)}$$

and where T_2 is the repair turn-around time. The first term on the right-hand side of (9) represents the orders with no carcasses for repair. The second term represents the orders that have carcasses for repair. Substituting (9) into (8) yields the solution:

$$Z = DL_2 = (D-G)L + GT_2 \qquad \textbf{(10)}$$

The partial derivative of equation (7) with respect to Q is taken and the result is set equal to zero. With assumptions stated in Maher (1993), this yields the following equation for the EOQ (Q^*_{PR}):

$$Q^*_{PR} = \sqrt{\frac{8(D-G)A}{IC}} . \qquad \textbf{(11)}$$

The repair model is similar in construction to the repair procurement model in (7). The total variable cost for the repair sub-model is given by the following equation:

$$\text{TVC}_{\text{RR}} = \frac{4\text{Min}(D,G)}{Q_2} A_2 + IC_2\left(\frac{Q_2}{2} + R_2 - Z_2 + B_3\right) + \frac{4\,l\,E\text{Min}(D,G)}{Q_2} B_4 , \qquad \textbf{(12)}$$

where,

C_2	~ Unit repair cost	Z_2	~ Repair problem variate
A_2	~ Cost to prepare a repair order	T_2	~ Repair turn around time
Q_2	~ Repair quantity	B_3	~ Expected # of backordered units
R_2	~ Repair reorder point	B_4	~ Expected # of backordered requisitions

In the repair model, the leadtime demand for the repair system (also known as the repair problem variable or Z_2) is the product of the quarterly demand and the repair turn around time, DT_2. This is used in (7) for calculating the optimal repair quantity:

$$Z_2 = DT_2 \qquad \textbf{(13)}$$

To determine the optimal repair quantity, the partial derivative of equation (12) is taken with respect to Q_2. Using the assumptions found in Maher (1993), the economic repair quantity is computed as

$$Q_2 = \sqrt{\frac{8\mathrm{Min}(D,G)A_2}{IC_2}}\ . \qquad \textbf{(14)}$$

Computing reorder levels for the two models separately created shortfalls in the repair model. The model calculates the number of carcasses to be repaired. However, at times, there were not enough NRFI items in stock to cover the required repair quantities of an item. This "carcass constrained" condition resulted from the repair safety level being greater than the procurement safety level (Grunzke, 2001). To fix the problem, the computation of safety levels for both procurement and repair were integrated. A single risk equation is used to compute these levels and is constrained between 0.01 and 0.45 in the same way as the consumable risk. The integrated RISK formula became

$$\mathrm{RISK} = \frac{IC_3 D}{IC_3 D + lEW}, \qquad \textbf{(15)}$$

where C_3 is a weighted average unit/repair cost computed by the following equation:

$$C_3 = \frac{G}{D}C_2 + \left(1 - \frac{G}{D}\right)C\ . \qquad \textbf{(16)}$$

The procurement reorder point, R, is computed in the same manner as the consumable model:

$$R = DL + GL + GT_2 + \text{safety level}. \qquad \textbf{(17)}$$

The repair level, R_2, is:

$$R_2 = DT_2 + \text{safety level}, \qquad \textbf{(18)}$$

where the safety levels used in (17) and (18) are the same.

C. SAFETY LEVELS

Safety levels are set as cushions against expected fluctuations in leadtime demand to prevent a stockout when actual demand exceeds forecasted demand. The safety level is the difference between the reorder level and the mean demand during leadtime. Calculation of the safety level depends on qualification of an acceptable level of risk of a stockout. If NAVICP is willing to accept a lower level of risk, the safety level is

increased, which in turn increases the reorder level. On the other hand, higher levels of risk lead to lower reorder and safety levels.

The calculated value of RISK from (15) is used to compute safety levels. If leadtime demand is assumed to be normally distributed, the risk value transforms into the number of standard deviations from mean leadtime demand to which the safety level must be set. Equations (5) and (6) refer. An important component of this RISK calculation is the shortage cost, l. The shortage cost directly influences safety levels.

D. SHORTAGE COSTS

Shortage costs, also known as backorder costs, are the imputed costs of a stock out. The NAVICP has no formal calculation to compute shortage costs (Higgins, 2001). However, there is a non-linear program used to assist NAVICP in the assignment of shortage costs (Ackart, 2001). Assignment of shortage costs are generated based on the cost of the item, its demand, the military essentiality of the item and the type of requisition. A stock replenishment will not "cost" as much as a direct-turn-over requisition if the item is out of stock. In reviewing equation (15), the shortage cost, l, is adjusted to achieve the desired RISK level. If the shortage cost increases (holding everything else constant), the RISK decreases, which results in higher safety levels. It is important to note that if this cost is set too low, there may not be enough stock on hand to meet expected demands. The investment in safety levels and holding costs must be weighed against the ordering and shortage costs; the optimal costs are based on forecasted demand and the variability of that demand.

E. LEVELS SETTING SEGMENT INDICATOR (LSSI) MATRIX

To assist in computing the levels investment, NAVICP uses the Levels Setting Segment Indicator (LSSI) matrix to segregate all aviation repairable items into four demand and 11 cost categories.

In the LSSI matrix, focus pool repairables, discussed in Chapter I, are divided into two demand categories, one category having quarterly demand greater than 20 and the other having less than or equal to 20. The remaining two demand categories contain all

other non-focus pool repairables with one having a quarterly demand greater than eight and the other having less than or equal to eight.

In addition to demand, the items are further segregated by a cost criterion. This "cost" is a weighted cost based on the repair price and the replacement price for each individual NIIN. The replacement price is the price NAVICP pays for a new item, whereas the repair price is the cost of performing the repair of a NRFI item. The following algorithm[6] is used to compute the weighted cost for each item:

If RII = 'N' or $B074 = 0$ then $C^* = B055$,

else if $B074A \geq B074$ then $C^* = B055A$,

$$\text{else } C^* = \frac{B074A}{B074} B055A + \left(1 - \frac{B074A}{B074}\right) B055,$$

where,

RII ~ Repair item indicator	C^* ~ Weighted average cost
B074 ~ Quarterly demand forecast	*B055* ~ Replacement cost
B074A ~ Quarterly regeneration forecast	*B055A* ~ Repair cost

Table 2.1 displays the eleven C* intervals used by NAVICP (Pinson, 2002). The cost breaks were computed to ensure each cell had roughly equal numbers of items in them.

[6] The BXXX terms listed in the weighted cost algorithm are Data Element Numbers (DENs) used in the UICP.

LSSI COST CATEGORY	COST INTERVAL
A	$0 < C^* \leq \$800$
B	$\$800 < C^* \leq \$1,400$
C	$\$1,400 < C^* \leq \$2,200$
D	$\$2,200 < C^* \leq \$3,200$
E	$\$3,200 < C^* \leq \$4,500$
F	$\$4,500 < C^* \leq \$6,300$
G	$\$6,300 < C^* \leq \$9,200$
H	$\$9,200 < C^* \leq \$14,000$
I	$\$14,000 < C^* \leq \$24,000$
J	$\$24,000 < C^* \leq \$44,000$
K	$C^* > \$44,000$

Table 2.1: Weighted Cost Categories Used in the FY 2002 LSSI Matrix. The cost, C*, is a weighted average of replacement cost and repair cost.

Table 2.2 shows the number of items in each LSSI cell.

	A	B	C	D	E	F	G	H	I	J	K
1	1043	1166	1036	824	753	528	449	402	308	183	162
2	207	270	280	247	217	154	152	146	131	84	57
3	127	140	193	151	136	128	84	90	99	56	43
4	47	86	124	113	96	81	66	69	45	31	31

Table 2.2: FY 2002 LSSI Matrix Showing Numbers of Items in Each Cell. The highlighted cells contain focus pool items. The eleven cost categories are ordered from "A" (lowest) to "K" (highest). The non-focus pool demand categories are "1" (lowest) and "2" (highest) in the left margin of the table. The focus pool demand categories are "3" (lowest) and "4" (highest).

Each of the 44 cells of the LSSI matrix is assigned a shortage cost. That shortage cost is used in the UICP model for all items within each LSSI cell to compute the RISK. The following three objectives guide the LSSI segmentation process and the setting of shortage costs for each cell: (1) minimization of safety level investments; (2) attainment

of an average SMA for each cell between 70 and 90 percent; and (3) attainment of an overall SMA of 85 percent (Kolibabek, 2002).

F. COMPUTATION AND RESEARCH EVALUATION SYSTEM (CARES)

The Computation and Research Evaluation System (CARES) is an application in the UICP designed to provide NAVICP management with a tool to analyze and evaluate alternative inventory management policies prior to their implementation in the UICP (NAVSUP, 1993). The model replicates the UICP levels setting computations and projects financial, inventory and performance statistics. Inventory statistics of interest include dollar investment in reorder levels and in safety levels. The performance statistics include projected SMA, Average Days Delay and Average Days Delay for Delayed Requisitions. These statistics are analyzed and evaluated to determine appropriate parameter settings to meet SMA goals and to meet budgetary limitations. Shortage costs, holding cost rates, risk and safety level constraints are some of the parameters used in CARES.

III. REQUISITIONING PROCESS

In this chapter, aspects of the Navy requisitioning process that affect Logistics Response Time (LRT) are described. An understanding of the factors that affect LRT can help to define policies that lead to a reduction in LRT, thereby promoting more efficient inventory management practices.

A. REQUISITION GENERATION

Upon the failure of a weapon system due to a part failure, the responsible division on board a ship or in a squadron generates a requirement in the ship's maintenance system. The supply department's automated requisitioning program interfaces with the maintenance system and generates a requisition number. The requisition number is made up of three parts. The first part contains two elements: the service designator and the unit identification code (UIC). The service designator indicates what type of activity ordered the part. There are three service designators used in the Navy. An "N" indicates the requisitioner is a neutral or shore activity such as Naval Air Station, Oceana, Virginia. Units assigned to the Pacific fleet use an "R" as their service designators. Atlantic fleet units use a "V". The UIC is a five-digit number that uniquely identifies each command in the Navy and Marine Corps.

The second part of the requisition number is the Julian date. This is a four-digit number made up of the last number of the year and the sequential number of the day of the year with January 1 being 001. For example, March 1, 2002 would be 2060.

The third part of the document number assigned by the supply department is the serial number. It identifies which division within the organization ordered the part. Figure 3.1 has an example of a requisition number from the USS ESSEX (LHD 2).

R21533-2060-8263

R – Service Designator for Pacific Fleet
21533 – Unit Identification Code for USS ESSEX
2060 – Julian Date for March 1, 2002
8263 – Serial Number for Food Service Division

Figure 3.1: Sample Requisition Number

B. LOGISTICS RESPONSE TIME (LRT)

The Department of the Navy is concerned with the amount of time it takes the supply system to ship parts to its customers. In the Materiel Management Directive, Logistics Response Time (LRT) is identified as the primary metric to gauge effectiveness of the supply system (DOD, 2001). The LRT clock starts with the date of the requisition and ends when the customer posts the receipt of the item in the automated supply system.

Logistics Response Time consists of twelve "nodes". Each node is measured in days and recorded for future reference (DAASC, 2002). The research described in this thesis is concerned with overall LRT, with particular attention to the Inventory Control Point response time (also known as the *initial source processing time* in DAASC, 2002) and the process and shipping time. These two LRT nodes are discussed below.

1. Inventory Control Point Response Time (ICPRT). ICPRT is the elapsed time between receipt of a requisition at NAVICP, and the issuance of a material release order (MRO) to a stock point for ready-for-issue parts. This time is of particular importance to the NAVICP because it measures the time it takes NAVICP to take positive supply action on a requisition. Positive supply action refers to the issuance of a release order to a stock point storing the part.

ICPRT is synonymous with average days delay (ADD). ADD is the average number of days it takes NAVICP to issue a MRO for all requisitions including those filled immediately and those backordered. A sub component of ADD, average days delay for delayed requisitions (ADDR), is the average number of days it takes NAVICP to fill backorder requisitions. NAVICP's goal is to minimize ADD across all items.

2. Process and Shipping Time. This is the elapsed time between the issuance of a material release order, and the posting of receipt by the customer in the automated supply system. Receipts are electronically transmitted to NAVICP. Processing and shipping time is the largest contributor to LRT in most requisitions, but one over which NAVICP has little control.

Logistics Response Time is the sum of ICPRT, the process and shipping time, and the order time[7]. For the purpose of this thesis, the requisition date is assumed to be the same as the ICP receipt date. As an equation, LRT is written as

[7] Order time is the time from the requisition date to NAVICP receipt date.

$$\text{LRT} = \text{ORDER TIME} + \text{ICPRT} + \text{PROCESS AND SHIPPING TIME.} \qquad \textbf{(19)}$$

Figure 3.2 illustrates this relationship.

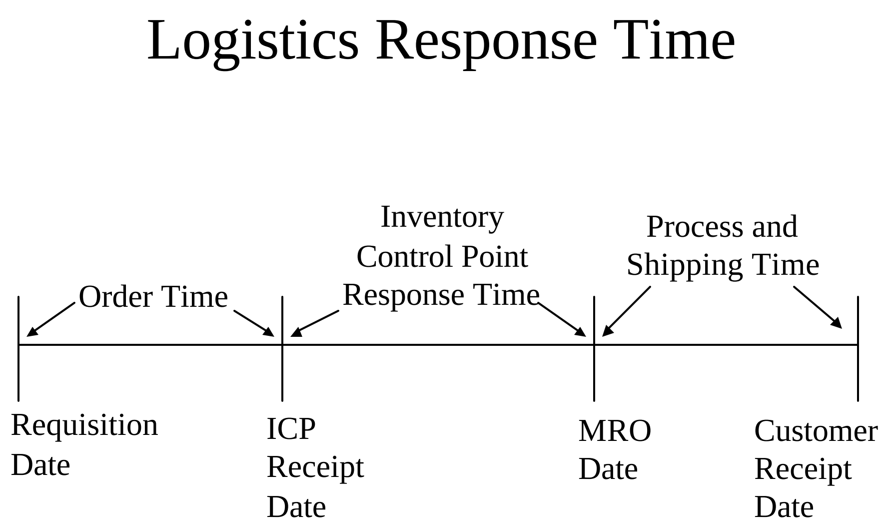

Figure 3.2: Timeline of Logistics Response Time. Starting with requisition date and ending with customer receipt date.

C. CAUSES OF HIGHER LOGISTICS RESPONSE TIMES

There are several attributes of the logistics system and of the requisition itself that may increase Logistics Response Times. This section addresses the following eight attributes: inventory control point response time, issue type, requisition type, priority, material location in relation to customer location, mode of transportation, delays in customer receipt and loss of material

1. <u>Inventory Control Point Response Time (ICPRT)</u>. There are a number of factors that contribute to response time delays through their effect on ICPRT. Three of the most important factors are discussed below.

a. <u>Administrative Leadtime (ALT).</u> The time it takes the procurement agent to award a contract is known as the administrative leadtime. This time could potentially inflate ICPRT because of contract competition, price negotiation and technical package production. Competition takes up to thirty days in order to give

potential vendors the opportunity to bid for contracts of high cost items. A second reason for increased ICPRT is price negotiation. The vendor may desire to increase the price of an item that the NAVICP deems unfair. This leads to contract negotiations that increase ALT. A third reason the contract process could potentially increase ALT is the technical package production. The vendor is responsible for proving it can produce spare parts that meet all technical specifications (called for by designing engineers) both in design and in performance.

b. ***Production Leadtime (PDLT).*** Once a contract is awarded, the vendor manufactures the items. The time it takes to complete the manufacturing is called the production leadtime. Delays in production due to changes in plant configuration inflate PDLT. Another cause of inflated PDLT is a lack of spare parts needed to manufacture the end item. This is due to the vendor's poor production planning. However, the NAVICP and ultimately the customer suffer because of the increased leadtime. The customers suffer because they do not receive their parts in a timely manner. NAVICP is affected adversely because higher "working" inventory levels are needed to cover leadtime demand.

c. ***Repair Turn Around Time (RTAT).*** Repair turn-around-time (RTAT) is the time it takes the repair depot to repair an item. RTAT can be inflated due to shortages of spare parts that are necessary to repair an item. Improper tooling can also cause the RTAT to increase.

2. **Issue Type.** An issue from NAVICP can be one of three types: immediate, backorder, or non-stock. An immediate issue is one where the item is processed when there is material available for immediate release. A backorder issue increases LRT due to a shortfall of stock items available for immediate issue. Higher LRTs are attributed to backordered issues. A non-stock issue is one for an item that is not-carried in a retail inventory and that is controlled more closely by NAVICP. An item that is issued in this respect requires adjusting or preparation before it can be issued to the customer.

3. **Requisition Type.** There are three types of requisitions that NAVICP receives from customers. Direct-turn-over (DTO) requisitions are for items that will be used for repairing aircraft components immediately upon receipt. By contrast, stock

requisitions are for items that replenish stock inventories. Stock requisitions experience longer LRTs because DTO requisitions take priority over them. The final requisition type is for outfitting items. These are items placed in a retail inventory level for the first time. They could also be used in initial aircraft construction.

4. Priority. The requisition priority can affect LRT. Priority indicates the urgency of need for an item by the command ordering the item. There are 15 primary priorities used by DOD activities. A priority of “1” is the highest and “15” is the lowest. The Navy primarily uses the following priorities: “1”, “2”, “3”, “4”, “5”, “6”, “11”, “12” and “13”. In most cases, a priority “1” requisition is filled before a priority “15”. Items with low SMA may experience significantly high LRTs as higher priority requisitions of that item are filled first (Nickel, 2001). Nickel (2001) discusses in detail the procedures the Navy uses to set requisition priorities including force activity and the urgency of need designators.

5. Material Location in Relation to Customer Location. Another important variable affecting LRT is the location of the material in relation to the customer. The Navy stores aviation spare parts at stock points all over the world, strategically placed close to fleet concentrations to minimize the shipping time. These NAVSUP managed stock points are called Fleet and Industrial Supply Centers (FISCs). There are FISCs located in San Diego, Norfolk, Jacksonville, Puget Sound, Pearl Harbor, and Yokosuka, Japan. The FISCs manage NAVICP item inventory levels at their locations. The Defense Logistics Agency (DLA) manages the Defense Distribution Depots (DDDs) where the stock is physically located.

When the ship is in port, LRT is relatively low unless the local stock point does not carry the item requisitioned or the item is not in stock. If this occurs, the part is shipped from another stock point. However, with the advent of logistics based contracts, more and more responsibilities are being placed on the vendor including inventory forecasting and storage. This means the stock points of some items are located near the manufacturer and not the fleet. As a result of this change in policy, LRTs could increase. For example, if a part is ordered from a ship located in San Diego and the part is located at Lockheed Martin’s manufacturing facility in New Jersey or at FISC Norfolk, the LRT is generally higher.

The ship's schedule could increase LRT. For example, suppose a ship gets underway on a Monday for three weeks to participate in a fleet exercise. If a part ordered arrives at its storage shed the next day, it will stay there until the ship returns. Upon the ship's return, the part is "received" and "posted". The increase in LRT is at least three weeks.

On deployments, attempting to alleviate the problem of high LRT, the ship's supply department issues a Fleet Freight Routing (FFR) message to DOD logistics agencies and the Navy supply system. This FFR message identifies the ports the ship is scheduled to visit and the dates to forward the ship's ordered parts to those ports. The homeport FISC ensures parts ordered by the ship are forwarded to ports as directed by the FFR. This delays the parts being received by the ship. Another aspect that could increase LRT is the changes in a ship's schedule. Scheduled port visits can be cancelled. If this happens, the Supply Department must issue a new FFR instructing the supply infrastructure in the forward deployed region as well as the homeport to reroute its parts to other locations. Again, this will add to the LRT of some requisitions increasing overall LRT for a given NIIN.

6. <u>Mode of Transportation.</u> The mode of transportation has a significant impact on Logistics Response Time. There are many forms of transportation the Navy uses to transport an item to the customer. Air shipments are the most common mode of transportation. In particular, express shipments via FEDEX and UPS are increasing. Creative contracts with shippers are locating parts in warehouses closer to these shippers, which ensures faster response times.

Another mode of transportation utilized by the Navy is the United States Postal Service. While this is a reliable source of transporting parts, it is one of the slowest. Another problem with the mail is the packaging of material. Some packages are labeled with the final destination only. The requisition, which displays the ordering division, is often missing from the label. This package is normally placed in the back of the ship's post office since no division claimed it. When the package is finally opened several days later, the part is delivered to the division that ordered it. The receipt is delivered to the supply department for processing days after the material was received on board. This inflates LRT.

7. Delays in Customer Receipt. Ships underway are delayed in receiving a part. However, there is another delay that is worth mentioning. There may be a delay in posting the receipt by the Supply Department. There could be a number of reasons this takes place. DTO requisitions could be turned over to the ordering divisions without the Supply Department retaining the receipt. The supply personnel must then track down the divisions and find the receipts. Another reason for increased LRT is the Supply Department holding off on posting stock receipts until all materials are properly placed in storerooms.

8. Loss of Material. A final cause for inflated LRTs is lost material. The DOD Supply system ships thousands of parts each day. Each homeport has multiple ships assigned to it. There are thousands of parts being received at the homeport supply centers. With many parts in a small area, parts are misplaced. Some of the parts are missing labels, which means the supply personnel cannot identify which ship ordered the part and in turn inflates LRT.

Ships and squadrons also misplace parts. With hundreds of parts coming on board, an item is placed in a storeroom and may not be found for days. Shipboard receipt processes have improved dramatically where the Supply Officer receives a list of parts received by the homeport supply center. Once the receipts have been posted to the supply system, a report can be generated listing the parts that are missing. This is especially important when the missing part is a repairable.

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IV. DATA USED IN THE ANALYSIS

In this chapter, the Defense Automatic Addressing System Center (DAASC) and NAVICP data bases are described, along with the methodology that was used to extract the data that were used for analyses. The DAASC data base consists of all requisitions for Naval aviation repairable items received in FY 2001, and contains the following fields: national item identification number (NIIN), Logistics Response Time (LRT), issue type, requisition type, priority, requisition number and issuing depot. The NAVICP data base contains FY 2002 management data on Naval aviation repairable items, including the NIIN, Levels Setting Segment Indicator (LSSI), standard price and local routing code (LRC). Appendix A gives a detailed description of all data fields contained in both databases.

The DAASC data base, which was the larger of the two sources of data, was extracted from the Logistics Metrics Analysis Reporting System/Customer Wait Time System (LMARS/CWT). LMARS/CWT contains the primary fields used in computing the LRT of each stock item managed by NAVICP including ICPRT and process and shipping time. The extracted LMARS/CWT data base used in this thesis contains 244,792 requisitions for 13,519 stocked items. There were data fields that contained invalid or missing entries. These items were removed from the data base, reducing the number of observations to 223,057 covering 12,739 unique NIINs.

The NAVICP data base was extracted from the Master Data File (MDF). This data base contains information for over 11,000 Naval aviation NIINs.

The MDF file was matched to the LMARS/CWT file by the NIIN data field. As a result, there were 7902 unique NIINs common to both data bases. Unmatched items in both data bases were removed. Of the 7,902 NIINs, there were 1,922 focus pool items and 5,980 non-focus pool items. These NIINs had a total of 165,570 requisitions between them. Table 4.1 breaks down the number of stock items within each LSSI cell after the invalid data were removed and the data base match was completed. The second number is the average SMA for each cell. The average LRT (in days) is the third number in each cell.

	A	B	C	D	E	F	G	H	I	J	K
1	592	759	656	524	465	324	269	260	174	108	77
	93.9	90.9	83.2	81.7	81.7	78.8	80.8	77.3	75.3	77.1	78.0
	32.8	30.9	33.6	38.8	35.4	41.4	36.4	55.5	53.3	50.0	50.0
2	189	257	271	217	203	129	138	129	124	67	48
	93.5	91.7	84.6	82.3	78.2	75.0	72.9	70.6	68.8	69.7	68.7
	28.3	29.6	31.9	35.7	35.7	42.8	39.2	40.5	64.4	69.5	68.7
3	109	126	185	143	130	122	78	83	88	53	39
	95.2	95.1	90.5	83.2	76.9	73.7	72.1	71.1	71.1	69.4	69.1
	30.1	25.3	30.4	29.8	32.3	37.5	42.5	48.6	48.1	69.3	69.5
4	47	84	119	109	93	79	65	67	43	30	30
	94.3	93.7	91.1	86.5	78.6	74.9	76.0	74.1	71.4	70.9	75.6
	29.2	24.4	23.8	29.4	26.8	30.3	38.8	40.9	47.6	4004	59.9

Table 4.1: LSSI Matrix After Removing Invalid Data. The highlighted cells contain the focus pool items. The eleven cost categories are ordered from "A " (lowest) to "K" (highest). In the left margin of the table, the non-focus pool demand categories are "1" (lowest) and "2" (highest). The focus pool demand categories are "3" (lowest) and "4" (highest). The top number in each cell represents the number of NIINs in that cell; the second gives the average SMA; the final number gives the mean LRT (in days).

V. METHODOLOGY AND ANALYSIS

In this chapter, a methodology is developed for classifying Naval aviation repairable items by their mean Logistics Response Times (LRT) values. This classification is then used to suggest an alternative segmentation of these items in order to promote their more effective management. This segmentation is then subjected to a comparison through the CARES analyzer in the UICP. The segmentation and CARES comparison results are presented in Sections E and F of this chapter, respectively.

In Chapter IV, the database that is used for this analysis is described. It consists of records for more than 165,000 receipted requisitions covering nearly 8,000 stock items in FY 2001. However, many of the stock items considered in the analysis had very few records. It was necessary to adopt an analytical approach that recognized the variability of estimated mean LRT across these items. Logistics Response Time was found to vary significantly by characteristics of the requisition, in particular the issue type, priority, service designator, and requisition type (defined in Chapter III). To deal with the effects of these variables on LRT, an analysis of variance (ANOVA) model is developed to explain the variance of LRT. The results of the ANOVA are used to calculate confidence bounds for mean LRT. Before presenting the results of the analysis, the analytical methodology is described.

A. ANALYSIS OF VARIANCE (ANOVA) MODELING

In this section data analysis is used to develop a rule for classifying Naval aviation repairable items into the following three categories: (1) mean LRT greater than 14 days (High LRT), (2) mean LRT less than or equal to 14 days (Low LRT), and (3) Indeterminate. As noted in Chapter I, the Navy has adopted the goal of achieving mean LRT of less than or equal to 14 days by FY 2005. An "Indeterminate" category is needed because the variability of estimated mean LRT for a particular item might not allow it to be classified into one of the other two categories with 90 percent confidence.

Figure 5.1 illustrates how the Navy performed in FY 2001 relative to the FY 2005 standard of 14 days. It is seen that almost half of Naval aviation repairable items fall short of this goal. The thesis research is oriented to the FY 2005 goal to highlight the

management effort needed to bring about the necessary improvement within a short time frame.

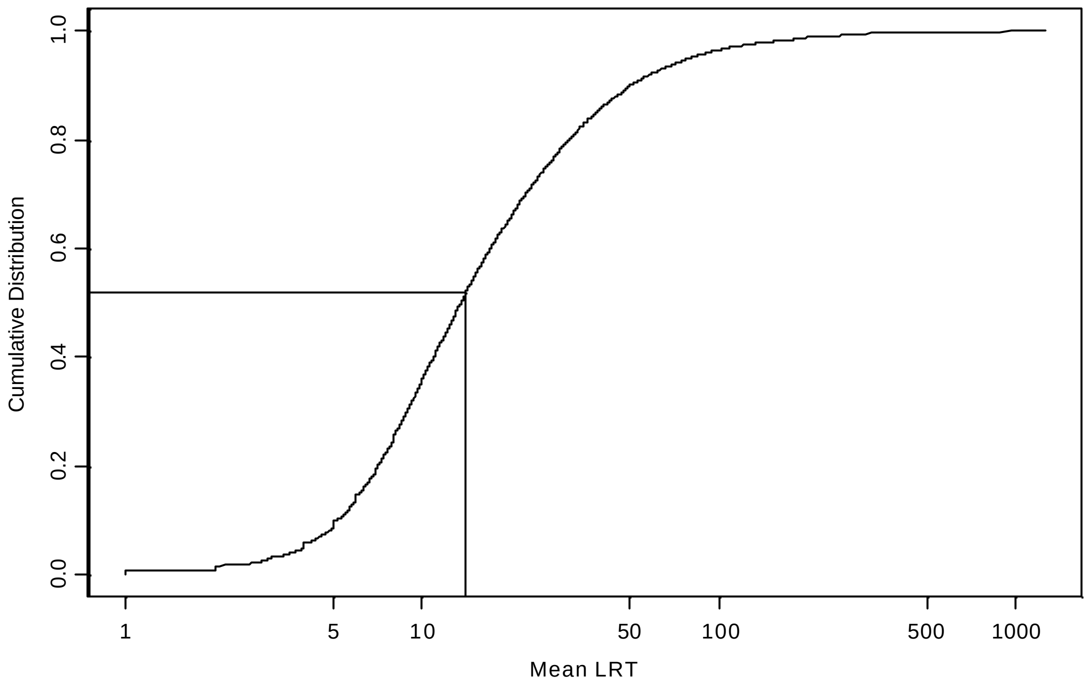

Figure 5.1: Cumulative Distribution Plot of Mean LRT Values (in days) for 7,902 Naval Aviation Repairable Items, FY 2001 Data. The horizontal and vertical lines in the plot indicate the 14-day LRT goal for the Navy by FY 2005. Only 52 percent of these items met the 14-day standard.

Classification of stock items by estimated LRT means is subject to error due to the variability of sampling. Almost one-sixth of the 7,902 items depicted in Figure 5.1 had a sample size of only one. Additional variability is caused by varying attributes of requisitions within the same item. Accounting for this variability allows for a description of the effect on LRT that is due to the item itself, as opposed to factors that could change from requisition to requisition.

The first step of this analysis is to identify the model or models for which ANOVA could be used. It is necessary to answer two questions: (1) Are LRT values approximately normally distributed, or should they be transformed to make this assumption valid? (2) Which explanatory factors should be included in the model? In

order to identify the best form for the ANOVA models, a "test set" of forty items is randomly selected from the 1,922 items from the focus pool. This is done by first dividing the focus pool into a two by two matrix, based on cost and demand. Ten items are selected from each of the four cells. Each test-set stock item is constrained to have at least five observations, and each cell at least 500 observations. The test set selected has 2,478 observations. Appendix B gives a description of the forty test-set items.

Analysis of variance models are based on an assumption that the residuals are normally distributed. Figure 5.2 shows that the histogram of the test-set mean LRT values are strongly right skewed. In order to achieve normality in modeling, logarithm transformations are often used. Figure 5.3 shows the histogram of the natural log-transformed[8] mean LRT values, which appears to be closer to the form of a normal density. This is additionally confirmed in Figure 5.4, which shows normal quantile-quantile (QQ) plots of the original and log-transformed mean LRT values. The near-linearity of the QQ plot after transformation indicates that it can be regarded as approximately normally distributed. The issue of normality is revisited later in Chapter V in the discussion of the ANOVA results.

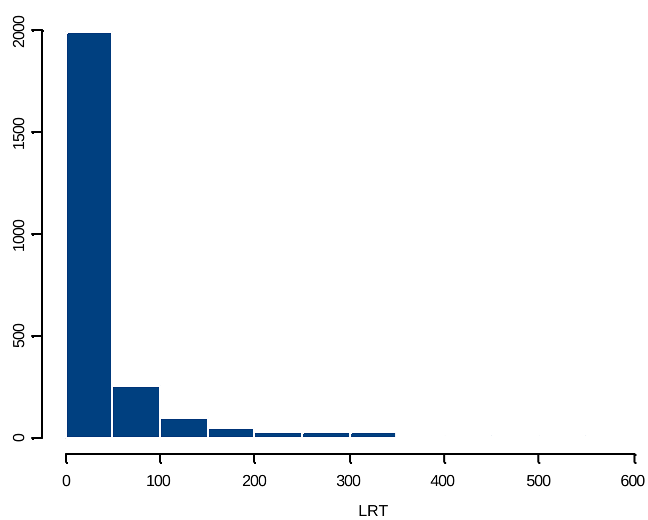

Figure 5.2: Histogram of LRT Values of the Test Set Items.

[8] Natural logarithms were used for Figure 5.2 and for all quantitative analyses. Equivalent results would be obtained if base-10 logarithms were used instead.

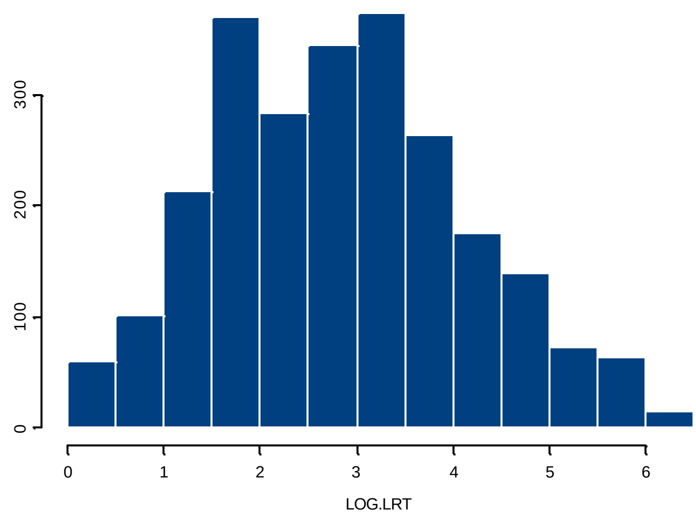

Figure 5.3: Histogram of Log-Transformed LRT of Test Set Items.

1. **Response Variable.** "Modified" LRT was used as the basis for this research. Modified LRT is the amount of time that elapsed from NAVICP receipt of a requisition to the customer receipt date. The purpose for making this modification is to remove elements from LRT before NAVICP receives the requisition. In the remainder of this thesis "LRT" will refer to "modified LRT" without further comment.

In ANOVA, it is sometimes necessary to transform the response variable in order to achieve near normality. Figures 5.2 and 5.3 clearly show that a log transformation is reasonable for an analysis based on LRT. For the purpose of this thesis, the natural logarithm of LRT is therefore used as the response variable.

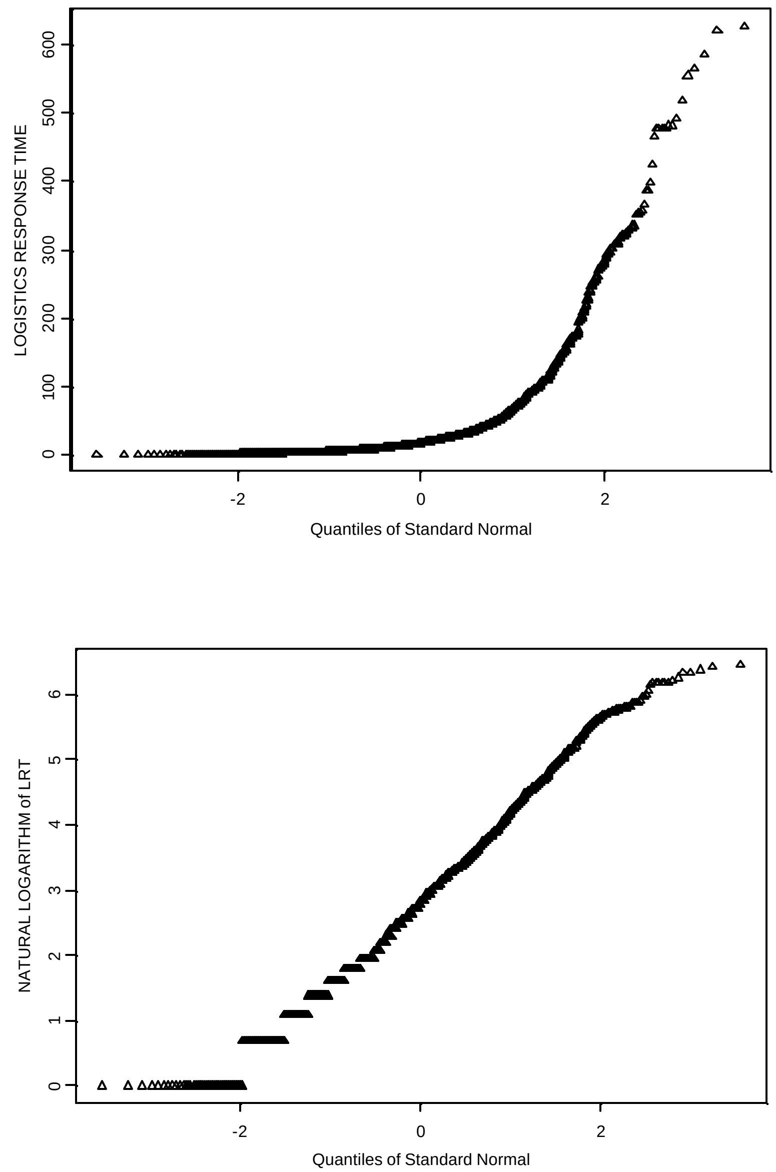

Figure 5.4: Normal Quantile-Quantile (QQ) Plots of Non-Transformed (top) and Natural Log-Transformed (bottom) Mean LRT of Test Set Items. Closeness of the plots to a linear trend is indicative of normality.

2. <u>Predictor Variables Used in the Analysis</u>. Based on analysis of data for the forty test-set items, five factors were identified as accounting for a significant amount of the variance of LRT across all NAVICP stock items. They are NIIN, issue type, requisition priority, the requisition type, and the service designation of the ordering command. A brief explanation of these predictor variables is given below.

a. ***National Item Identification Number (NIIN).*** The NIIN, or item, is not itself a predictor variable, except in the sense that it uniquely identifies the item. Logistics response times vary considerably by NIIN.

b. ***Issue Type.*** Issue type is a factor that assumes three values in the FY 2001 requisition data, indicating whether an item was released immediately, whether the issue occurred as the result of satisfying a backorder requisition, or whether the issue was classified as non-stocked. Graphical representation of the base-10 logarithm of LRT by issue type is shown in Figure 5.5. It is apparent from Figure 5.5 that the median LRT is highest for backorder issues.

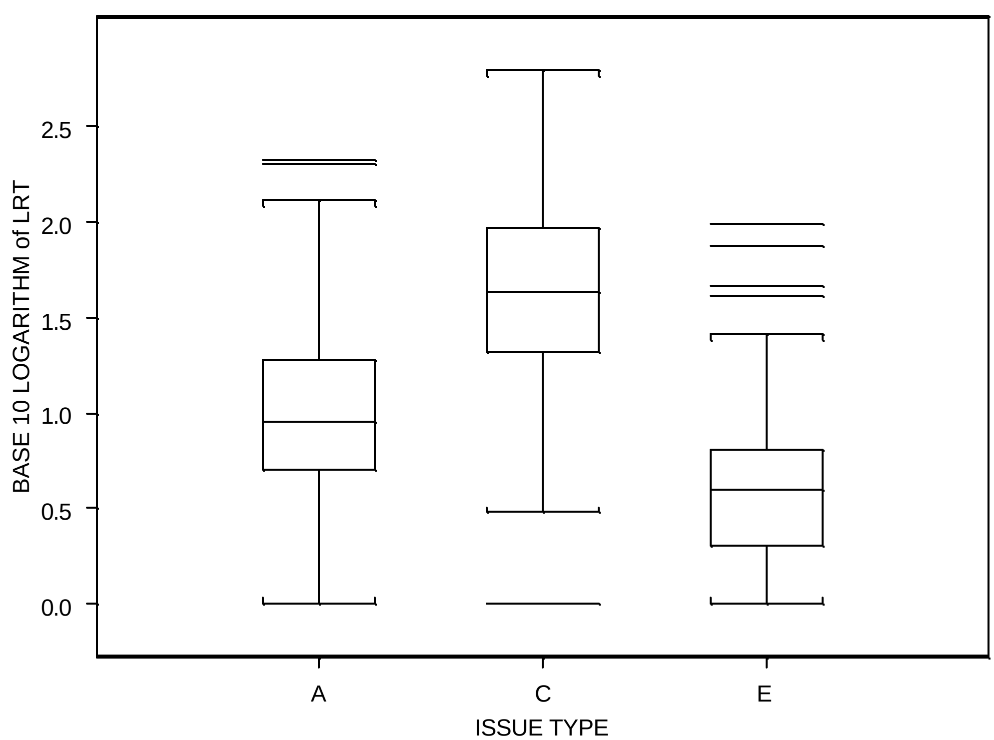

Figure 5.5: Boxplots of Base-10 Logarithm of Mean LRT by Issue Type for the Test Set Items. "A" is immediate issue. "C" is backorder issue. "E" is non-stocked issue. The backorder issue type has the highest median base-10 log. Immediate issues have the second highest and non-stocked has the lowest.

c. ***Requisition Priority***. Requisition priority (hereafter referred to as "priority") is a data element that indicates how critical the requisition is to the customer. The higher the priority, the more urgent the part is required by the end-user. NAVICP often classifies priority into three issue priority groups (IPGs). The first (IPG 1) is the highest priority group, consisting of priority codes one, two and three. The second highest priority group (IPG 2) consists of priority codes four, five and six. The lowest priority group (IPG 3) for the purpose of this thesis consists of all other priority codes. Figure 5.6 shows boxplots of the base-10 logarithms of LRT by the three IPGs for the 40 test set items. IPG 1 requisitions have a smaller range than IPG 2. It is apparent from Figure 5.6 that median LRT of IPG 1 requisitions is higher than IPG 2. IPG 3 has the highest median of the three issue priority groups.

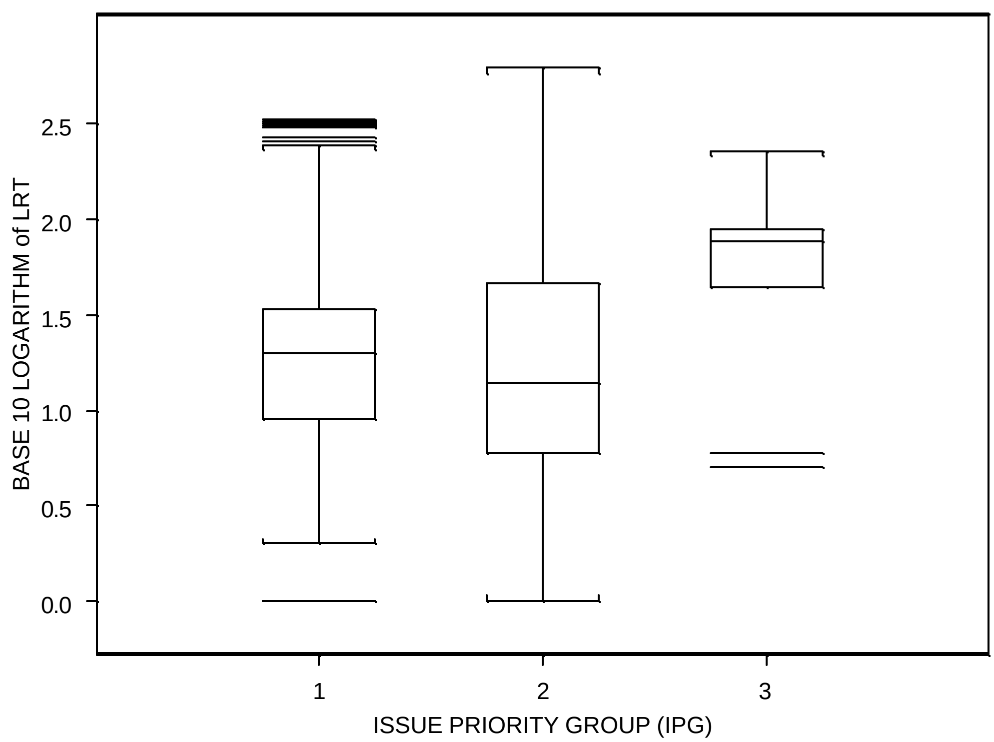

Figure 5.6: Boxplots of Base-10 Logarithm of Mean LRT and Issue Priority Group (IPG) for the Test Set Items. IPG 1 is the highest priority. IPG 3 is the lowest. IPG 1 Median LRT is higher than IPG 2 median LRT. IPG 3 has the highest median.

Higgins and Nickel (2001) conducted a simulation in which the mean waiting time to fill a requisition for a particular Naval repairable item was estimated in relation to the requisition priority. Under their model, it was found that the waiting time decreased with the higher priority of the requisition, when controlling for the service designator (defined below). Their findings were based on the analysis of one Naval aviation repairable item, and their results were in part determined by the assumptions of the model. The research conducted for this thesis, which was based on the analysis of 40 items in the test group and 7,902 items overall, found that the relationship of priority to LRT was less simple to characterize when considered with other factors simultaneously. It was found that the effect of priority on LRT differed substantially by the item.

d. ***Requisition Type***. There are three requisition types: stock, direct turnover, and outfitting. Outfitting requisitions occurred rarely in the FY 2001 data and therefore are not used in the analysis. Figure 5.7 shows boxplots of base-10 logarithm of LRT by requisition type. It is apparent from Figure 5.7 that the median of both requisition types is roughly the same. However, the range of data for stock requisitions is higher, which could indicate higher variability.

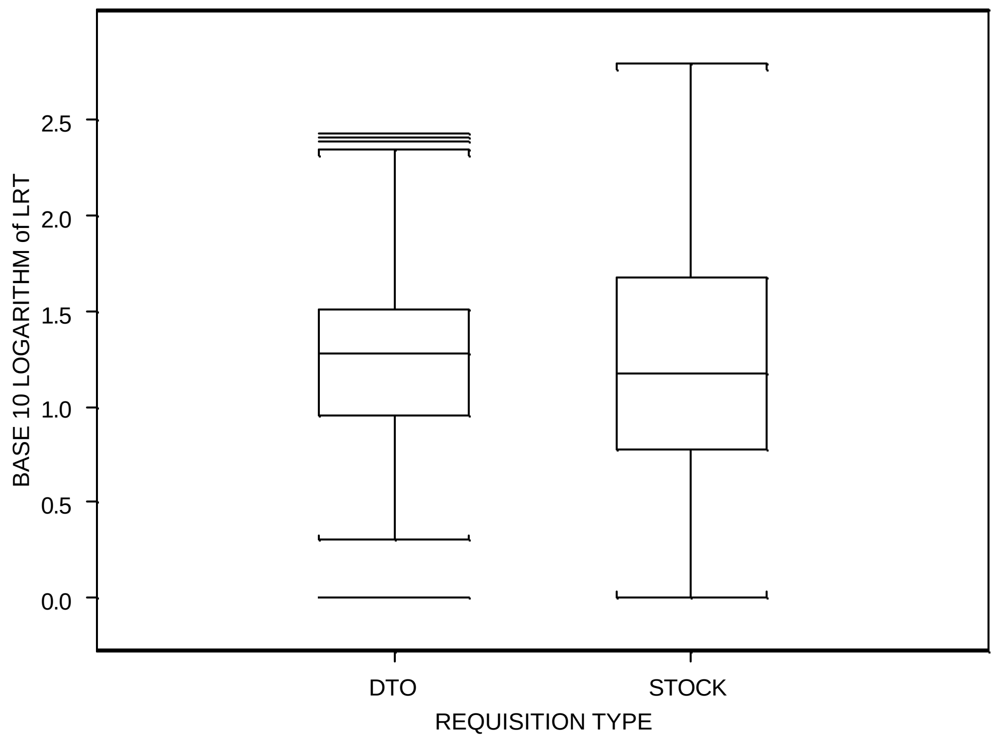

Figure 5.7: Boxplots of Base-10 Logarithm of Mean LRT by Requisition Type for the Test Set Items. DTO denotes direct-turn-over requisitions. The medians are roughly the same. Stock requisitions have wider range of LRT.

***e*. *Service Designator*.** The service designator was discussed in detail in Chapter III. The shore command service designator, "N", has a lower median base-10 logarithm of LRT than the Pacific and Atlantic commands as shown in Figure 5.8. This is due to the non-mobile quality of those commands; material always goes to the same destination unless the command moves to a new geographic location. The two fleet service designators, "R" and "V", have almost identical boxplots as shown in Figure 5.8.

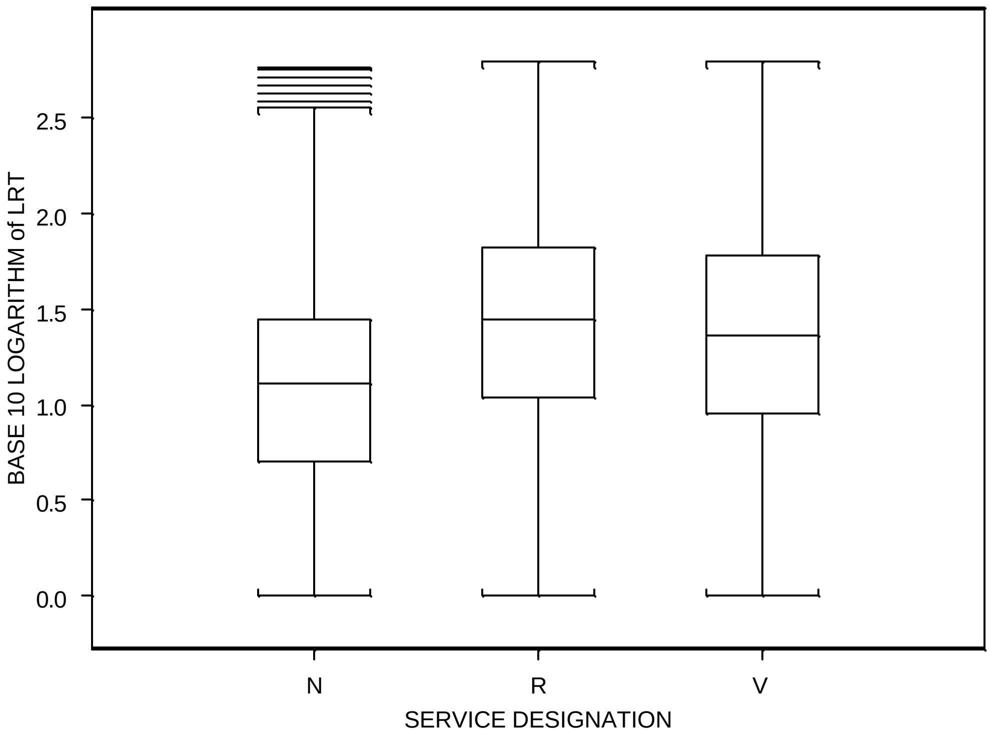

Figure 5.8: Boxplots of Base-10 Logarithm of LRT by Service Designator for the Test Set Items. Fleet activities have nearly identical boxplots. Shore activities have a somewhat lower median Base-10 Logarithm of LRT. The "N" indicates a shore activity; the "R", a Pacific Fleet unit; the "V", an Atlantic Fleet Unit.

f. ***Other Factors Affecting LRT***. These other factors are discussed in Chapter III and include mode of shipment, loss of material and delay in receipt posting by the customer, are not selected as predictor variables. To transport an item to the customer, there may be several modes of shipment utilized. Those other nodes were not available in the data provided and therefore are not used in the analysis. Loss of material and delays in posting receipts by the customer are not monitored by NAVICP and therefore are not used in the analysis.

3. **Model Development.** In this section the proper form of an ANOVA model to explain LRT is considered. For the factors in this analysis, ISSUE (issue type) assumes three possible values; IPG (issue priority group) assumes three possible values;

SVC.DES (service designator) assumes three possible values; and REQN (requisition type) assumes two different values. As noted earlier, the natural logarithm of LRT is considered as the dependent variable.

The first phase of the model development is to identify the correct form of the model to use. Ultimately, it is necessary to fit the models individually by item (NIIN). To have undertaken the process of model development on these items individually would have been a daunting task: there are nearly 8,000 different items in the FY 2001 requisition data. Furthermore, these items vary greatly by sample size, and by the presence of the various factor levels. Due to these considerations, the test set is used for model development. These test set items are described above in Section A of this chapter.

Using the test set data, a "baseline" ANOVA model consists of NIIN alone as a predictor variable. Results of fitting this model are shown in the first line of Table 5.1. The baseline model explains approximately 42 percent of the variance of LRT[9], and has a mean square error (MSE) of 1.0165. The baseline model represents using NIIN alone as a predictor of LRT. It is indeed a significant and important predictor, but at issue is whether the use of additional factors can explain an even larger percentage of the variance of LRT.

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[9] In ANOVA, the percent of variance explained is usually represented by R^2.

Model	MSE	R^2
LRT ~ NIIN	1.0165	0.416
LRT ~ NIIN + IPG + SVC.DES + REQN + ISSUE (Additive Baseline)	0.8502	0.513
LRT ~ NIIN + IPG + SVC.DES + REQN (Remove ISSUE)	1.0033	0.425
LRT ~ NIIN + IPG + REQN + ISSUE (Remove SVC.DES)	0.8552	0.510
LRT ~ NIIN + SVC.DES + REQN + ISSUE (Remove IPG)	0.8519	0.512
LRT ~ NIIN + IPG + SVC.DES + ISSUE (Remove REQN)	0.8506	0.512
LRT ~ $(\text{NIIN + IPG + SVC.DES + REQN + ISSUE})^2$ (Interactive Baseline)	0.5763	0.693
LRT ~ $(\text{NIIN + IPG + SVC.DES + REQN })^2$ (Remove ISSUE)	0.7413	0.599
LRT ~ $(\text{NIIN + IPG + REQN + ISSUE})^2$ (Remove SVC.DES)	0.6658	0.633
LRT ~ $(\text{NIIN + IPG + SVC.DES + ISSUE})^2$ (Remove REQN)	0.6055	0.673
LRT ~ $(\text{NIIN + SVC.DES + REQN + ISSUE})^2$ (Remove IPG)	0.5927	0.680

Table 5.1: Results of fitting ANOVA Models to the Test Set Data. Mean squared error and R^2 of the ANOVA models Formulated Using the Test Set Data with National Item Identification Number (NIIN), Issue Type (ISSUE), Issue Priority Group (IPG), Requisition Type (REQN) and Service Designator (SVC.DES). The fitted models are listed in decreasing significance when one factor is removed from the model then refit. The exponent of 2 indicates the model is one of second order.

Next, an "additive baseline" model is considered, which uses NIIN and all four previously identified factors (IPG, SVC.DES, ISSUE, and REQN) as additive effects. This additive baseline model explains 51 percent of the variance, with a MSE of 0.85 and is shown in the second line of Table 5.1. This represents a statistically significant, and substantial, improvement over the baseline model that used NIIN alone. Deleting each of the four additional factors in turn reveals that MSE increases the most when ISSUE is dropped from the model, which gives an indication of the importance of this factor.

Finally, a "second-order baseline" model is considered, which uses all of the factors of the additive baseline model, but also includes second-order interaction terms. These interaction terms allow for the relationship of LRT to the factors to vary across NIINs, and to be non-additive within each NIIN. The second-order baseline model explains 69 percent of the variance of LRT, with a MSE of 0.58 (Line 7 of Table 5.1), which represents a substantial improvement over the additive baseline model. Deleting one of the four factors (other than NIIN) in turn again reveals that the greatest reduction in performance occurs when ISSUE is dropped. The conclusions of this modeling exercise are (1) that a second-order model is superior to an additive model for explaining

the variance of LRT; (2) next to NIIN, ISSUE is the most important explanatory variable; and (3) that the other factors, while less important than ISSUE, nonetheless are significant explanatory factors.

The analysis of the test-set data, which is summarized numerically in Table 5.1, suggests that in fitting ANOVA models to the entire data set, individually by item, second-order models should be given preference to additive models, and the order of preference for explanatory variables (in decreasing order of importance) should be as follows: ISSUE, SVC.DES, REQN, and PRIOR. It is not possible to fit a "full model" in every case; some items did not have a full set of factor levels present for every explanatory variable. The model "closest" to the baseline second-order model that could be fit, using the hierarchy indicated above, is identified and used for each item. This analysis was conducted using the software package S-Plus® (Mathsoft, 1999). The S-Plus function CleanLRT, produced in Appendix C, was written to fit ANOVA models for each of the individual items.

An important assumption of the ANOVA model is that the residuals are approximately normally distributed. In Section A of this chapter, a natural logarithm transformation was found to be an effective means of removing the skewness that was present in the original LRT data, as shown in Figures 5.2 and 5.3. Figure 5.9, which is a quantile-quantile (QQ) plot of the residuals from fitting the second-order baseline model, further supports the use of the logarithm transformation. The QQ plot is nearly linear, which is indicative of normality.

B. CONFIDENCE BOUNDS FOR MEAN LOGISTICS RESPONSE TIME

The second step in the analysis is to develop a rule to classify mean LRT. The test-set NIINs are fit to the models using the CleanLRT function. The output file contains the "pre" and "post" ANOVA variances, the number of levels for each factor (ISSUE, IPG, REQN AND SVC.DES), the degrees of freedom, the sample size, and the mean logarithm of LRT for each NIIN. The data are used to construct 90% confidence bounds of the mean log (LRT) for each item by using the following formula:

$$\overline{x} \pm t_{(1-a/2,\mathrm{df})}\sqrt{\frac{\mathrm{MSE}}{n}}, \qquad \textbf{(20)}$$

where xbar is the grand mean, t is the t-distribution, a is 1 minus the confidence, df is the degrees of freedom, MSE is the mean squared error of the ANOVA model, and n is the sample size. To compute actual numbers, the results are exponentiated. These confidence bounds are used to classify a NIIN as having “High LRT”, “Low LRT”, or “Indeterminate” as described in Section A of this chapter. The results of the CleanLRT function and the confidence bounds for the test-set items are listed in Appendix D.

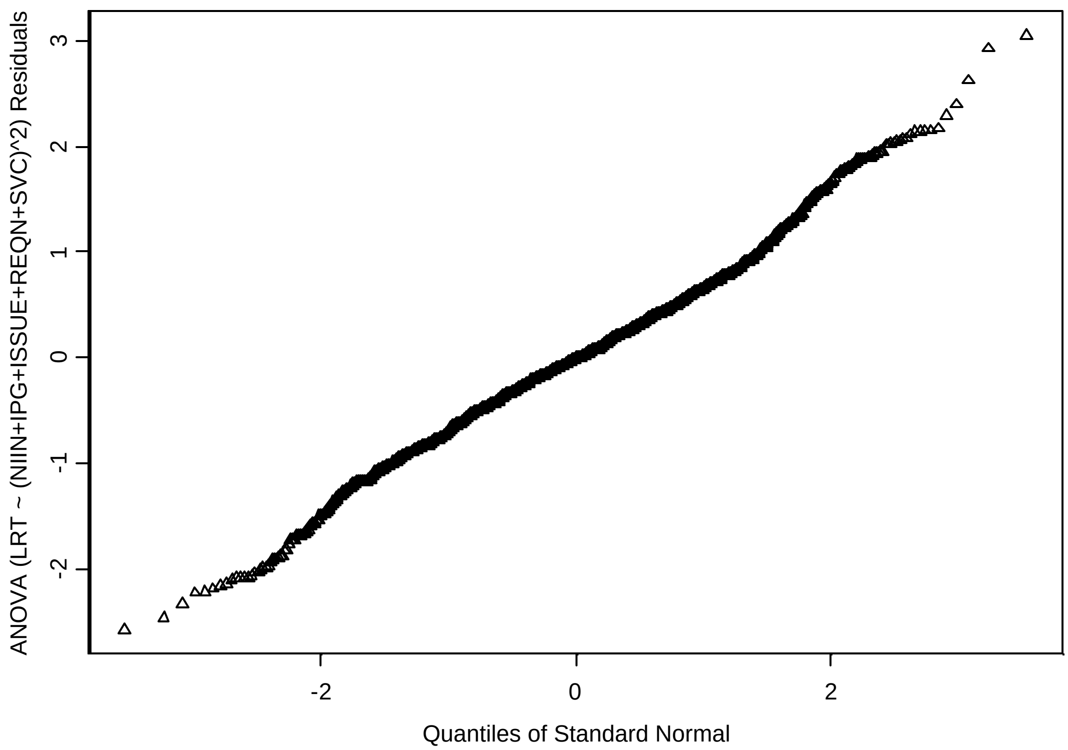

Figure 5.9: Normal Quantile-Quantile (QQ) Plot of Analysis of Variance (ANOVA) Residuals. The ANOVA model is logarithm of LRT with NIIN, issue type, issue priority group, requisition type and service designator in two-way interactions. Near linearity indicates approximate normality and thus a good fitted model.

Of the 7,902 Naval aviation repairable items, 53 percent exhibited a reduction in variance of log(LRT) after being fit to one of the previously described models. Due to no ANOVA model being fit, nearly 40 percent exhibited no change in variance. The reduction in variance is investigated for a particular NIIN that was included in the analysis.

The item in question is the fuel assembly nozzle support, NIIN 01-315-1717, which is used in aircraft engines. It is a low cost, low demand focus-pool item. The variance of LRT before the ANOVA is 0.972. After fitting the ANOVA model, the variance reduces to 0.150. This section investigates why this occurs. The nozzle has all three service designators, two out of three issue types, two out of three priority groups and both requisition types within its 279 observations. This equates to 271 degrees of freedom. The grand mean of the log (LRT) is 2.905624

There were five commands that ordered the fuel nozzle. The LRT for the 279 requisitions from these commands varied from two to 58 days. The top histogram in Figure 5.10 clearly shows a bimodal distribution of the log (LRT). In this NIIN's case, this is due to high priority requisitions having high LRTs and low priority requisitions having low LRTs. However, the residuals in the bottom graph of Figure 5.10 indicate near normality of the data. Table 5.2 gives a breakdown on priority, requisition type, and issuing depot for each ordering command with the frequency and average LRT for each. The numbers of IPG and requisition type requisitions are almost identical. Intuitively, the DTO requisitions would have the lower LRT and the stock requisitions would have the higher LRT. This is not the case with the IPG 1 DTO requisitions from Naval Air Station (NAS) Whidbey Island.

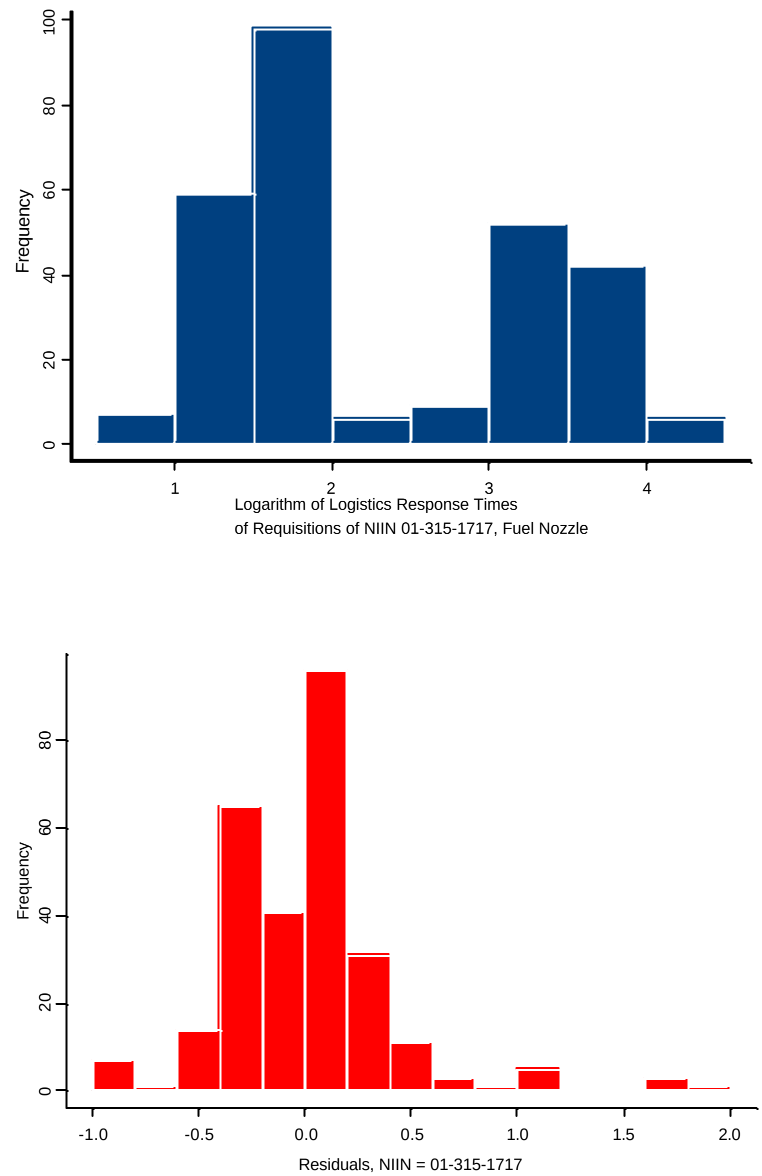

Figure 5.10: Histogram of Log (LRT) of NIIN 01-315-1717, Fuel Nozzle Requisitions (top) and Their Residuals (bottom). Notice the bimodal properties with peaks around log (5)(between 1.5 and 2.0 in the graph) days and log (34)(between 3.0 and 3.5 in the graph) days in the top graph. Also notice the "near" normality in the residual histogram.

	Priority		Requisition Type		Issuing Depot			
	IPG1	IPG2	DTO	STK	NZZ	PKZ	SDH	SDM
NAS Whidbey Island (N00620)	14 28.8	104 5.34	14 28.8	104 5.34	0 -	14 28.8	0 -	104 5.34
MALS12 (R09112)	0 -	1 40.0	0 -	1 40.0	1 40.0	0 NA	0 NA	0 NA
MALS14 (V09114)	2 5.50	69 6.94	2 5.50	69 6.94	0 -	0 -	1 5.0	70 6.93
AIMD Whidbey Island (N44329)	81 36.6	0 -	79 36.8	2 27.5	0 -	81 36.6	0 -	0 -
FISC YOKO (N62649)	0 -	8 7.75	0 -	8 7.75	0 -	0 -	0 -	8 7.75

Table 5.2: Breakdown of Issuing Depot, Issue Priority Group and Requisition Type for each Ordering Command for NIIN 01-315-1717, Fuel Nozzle. The Issuing Depots are (l to r) FISC Yokosuka (NZZ), NAS Whidbey Island (PKZ), Defense Depot Jacksonville (SDH) and Defense Depot Cherry Point (SDM). The top number gives the frequency; the bottom gives the average LRT for those requisitions in days

When looking at the LRT versus IPG in Table 5.2, the higher priority requisitions had higher LRTs. When looking at the LRT versus REQN.TYPE, the stock requisitions had higher LRTs. Finally, when looking at the LRT versus Service Designator, shore based commands had a bimodal distribution with a peak between four and six days and another around 33 and 34 days. NAS Whidbey Island had the lower LRT observations. However, its 14 DTO requisitions all had LRTs greater than 25 days.

Table 5.3 displays the different combinations of the factors the fuel nozzle requisitions had. Table 5.3 also shows the frequency and mean LRT of those combinations. It is apparent that high priority DTO requisitions from shore activities that were immediately issued had the highest mean LRT. On the other hand, lower priority stock requisitions from shore activities and Atlantic Fleet units that were immediately issued had the low LRT. However, this is the observation of a single NIIN. Each NIIN has a different combination of the four factors affecting LRT differently.

SVC.DES	IPG	REQN	ISSUE	Frequency	Mean LRT
Shore	1	DTO	Immediate	93	34.7
Shore	1	Stock	Immediate	2	27.5
Shore	2	Stock	Immediate	112	4.9
Pacific	2	Stock	Immediate	1	4.0
Atlantic	1	DTO	Immediate	1	4.0
Atlantic	1	DTO	Backorder	1	7.0
Atlantic	2	Stock	Immediate	65	5.5
Atlantic	2	Stock	Backorder	4	14.0

Table 5.3: Frequencies of Combinations of Service Designator, Issue Type, Requisition Type, and Issue Priority Group of Requisitions for NIIN 01-315-1717. Mean LRT is in days.

C. ITEM CLASSIFICATION USING CONFIDENCE BOUNDS

The final step in the analysis is the classification of Naval aviation repairable items using the results of the above analysis. The upper and lower 90 percent confidence bounds are used to classify an item as “High LRT”, “Low LRT”, or “Indeterminate”. An item is classified as High LRT if its 90 percent lower confidence bound is greater than 14 days. An item is classified as Low LRT if its 90 percent upper confidence bound is less than 14 days. An item is classified as Indeterminate if it cannot be classified as either High or Low LRT.

There are two cases where classifications are “Indeterminate”. The first is if the Navy’s goal mean LRT falls within the lower and upper confidence bonds. The variance, in this case, is too great to classify mean LRT as High or Low with high confidence. The second instance of indeterminate classifications occurs if the ANOVA model cannot be fit due to too few observations. In these cases, the items are classified in the “High” LRT category if the demand category was a “3” or “4”, indicating the item was in the focus pool. If the demand category is a “1” or “2”, the item is classified in the “Low” LRT category. Appendix D gives a detailed breakdown of the raw LRT classifications and the final LRT classifications for the test set NIINs.

D. PROPOSED SEGMENTATION

An alternate segmentation of Naval aviation repairable items based on cost, demand, and mean LRT is proposed in this section. The cost criterion in the proposed segmentation is a modified grouping of costs used in the FY 2002 LSSI matrix. In this alternative segmentation, there are six cost categories instead of the eleven used in the existing segmentation. The cost and demand categories used in the proposed segmentation is displayed in Table 5.4.

LSSI Cost Category	Cost Interval	LSSI Demand Category	Demand Break
1	0< C* ≤ $1,400	1	Non focus ≤ 8
2	$1,400< C* ≤ $3,200	2	Non focus > 8
3	$3,200 < C* ≤ $6,300	3	Focus Pool ≤ 20
4	$6,300 < C* ≤ $14,000	4	Focus Pool > 20
5	$14,000 < C* ≤ $44,000		
6	C* > $44,000		

Table 5.4: Cost and Demand Categories for the Proposed LSSI Matrix. Cost categories range from "1" (lowest) to "6" (highest). The non-focus pool demand categories are "1" (lowest) and "2" (highest) in the left margin of the table. The focus pool demand categories are "3" (lowest) and "4" (highest). The "8" and the "20" indicate quarterly demands.

The demand categories in the proposed LSSI matrix do not change.

The third criterion in the proposed LSSI matrix segmentation is the item's mean LRT classification as discussed in Section C of this chapter. The item is either classified as having High LRT, "H", or Low LRT, "L".

E. RESULTS OF ANALYSIS

The cost, demand and LRT segmentation criteria create a 48-cell matrix as opposed to the existing FY 2002 44-cell matrix. Table 5.5 shows the number of items assigned to each new LSSI cell. In addition to the number of items, Table 5.5 shows the average SMA and the mean LRT for each cell based on the FY 2001 requisition data.

The LSSI cell code is a four-digit alphanumeric code. The first letter is the LRT classification followed by the demand and cost categories. For example, the LSSI cell L3.4 contains 47 NIINs with an average SMA of 72.1 percent and a mean LRT of 12.4 days. This cell contains focus pool items that are described by low LRT, low demand and a weighted cost between $6,300 and $14,000.

	HIGH LRT Demand				LOW LRT Demand			
Cost	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
1	154 91.9 57.4	100 92.2 56.4	145 95.4 36.9	72 94.3 36.4	1197 92.3 28.4	346 92.5 21.2	90 94.6 12.5	59 93.6 13.5
2	145 82.6 71.1	104 84.2 69.3	183 87.1 44.3	116 88.6 40.0	1035 82.5 31.0	384 83.4 23.9	145 87.6 12.2	112 89.2 12.4
3	80 80.5 86.2	100 76.1 72.9	152 74.5 49.3	95 75.8 41.2	709 80.4 32.4	232 77.3 23.6	100 76.3 12.8	77 78.2 12.6
4	74 78.2 125.1	74 71.2 73.2	114 71.4 59.4	87 74.8 54.4	455 79.2 32.8	193 72.0 27.0	47 72.1 12.4	45 75.4 11.8
5	45 75.0 86.2	71 67.5 107.7	116 70.8 65.6	54 71.3 56.0	237 76.2 45.5	120 70.0 41.6	25 68.8 12.0	19 71.1 12.5
6	12 76.4 81.7	21 69.5 113.4	28 68.0 92.2	22 73.2 77.7	65 78.3 62.7	27 68.1 46.0	11 71.9 11.8	8 82.4 10.8

Table 5.5: Proposed LSSI Matrix. There are two LRT categories – High, "H", and Low, "L". Cost criterion ranges from "1" (lowest) to "6" (highest). Demand criterion "1" (low) and "2" (high) are non-focus pool items, "3" (low) and "4" (high) are focus pool items. The top number in each cell indicates the number of NIINs in that cell; the middle represents average SMA; the bottom represents the mean LRT. Highlighted cells indicate non-focus pool items to be moved to management attention due to High LRT.

The non-focus pool items in the High LRT category, highlighted in Table 5.5 can be added to management attention due to high LRT. Similarly, the focus pool items in the Low LRT category can be removed from the focus group due to the LRT falling below the Navy's goal. This is discussed further in Section F of this chapter.

Figure 5.11 shows the boxplots of SMA by the proposed LSSI matrix LRT/Cost categories. Notice the similarity with Figure 1.2 with regards to the downward trend of SMA for both High and Low LRT categories as cost increases with a slight upward trend at the highest cost category. The range of SMA within the higher cost items in LRT/Cost

categories “H6” and “L6” is still considerable compared to the existing FY 2002 LSSI matrix shown in Figure 1.2.

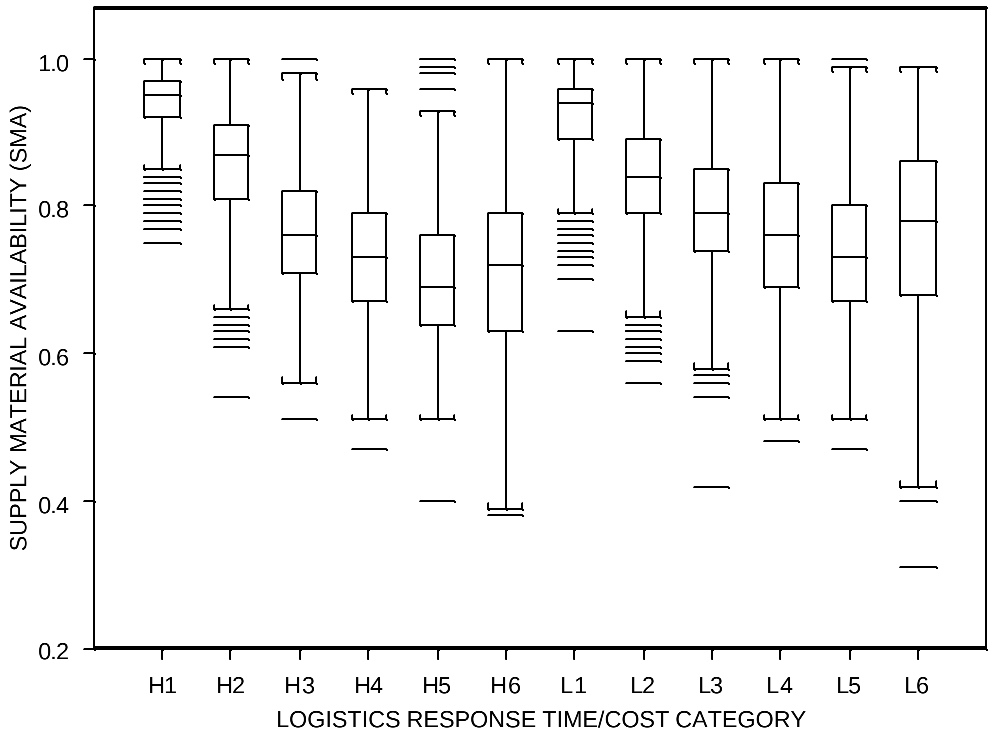

Figure 5.11: Boxplots of Supply Material Availability by the Proposed LSSI Matrix LRT/Cost Categories. The “H” represents high LRT. The “L” indicates low LRT. The cost ranges from “1” (lowest) to “6” (highest).

Figure 5.12 shows the boxplots of SMA by the proposed LSSI matrix LRT/Demand categories. It is apparent in Figure 5.12 that the median SMA for all eight LRT/Demand categories is roughly equal unlike the downward trend in Figure 5.11. A comparison of the boxplots in Figures 5.11 and 5.12 shows that SMA is constant across the LRT/Demand categories for both high and low LRT, whereas SMA has a downward trend across the LRT/Cost categories.

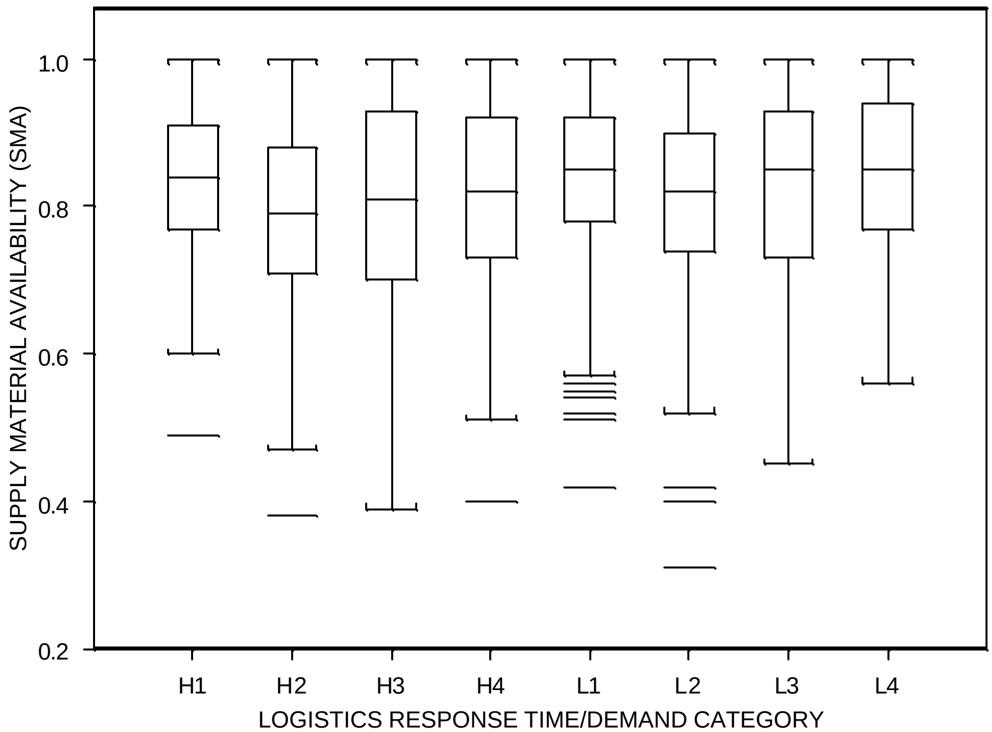

Figure 5.12: Boxplots of Supply Material Availability by the Proposed LSSI Matrix LRT/Demand Categories. The "H" represents high LRT. The "L" indicates low LRT. The "1" and "2" indicate low and high demand respectively for non-focus items. The "3" and "4" indicate low and high demand respectively for focus items.

Figure 5.13 shows the boxplots of base-10 logarithm of mean LRT by the proposed LSSI matrix LRT/Cost categories. Notice that median LRT increases as the cost increases across both the high and low LRT categories.

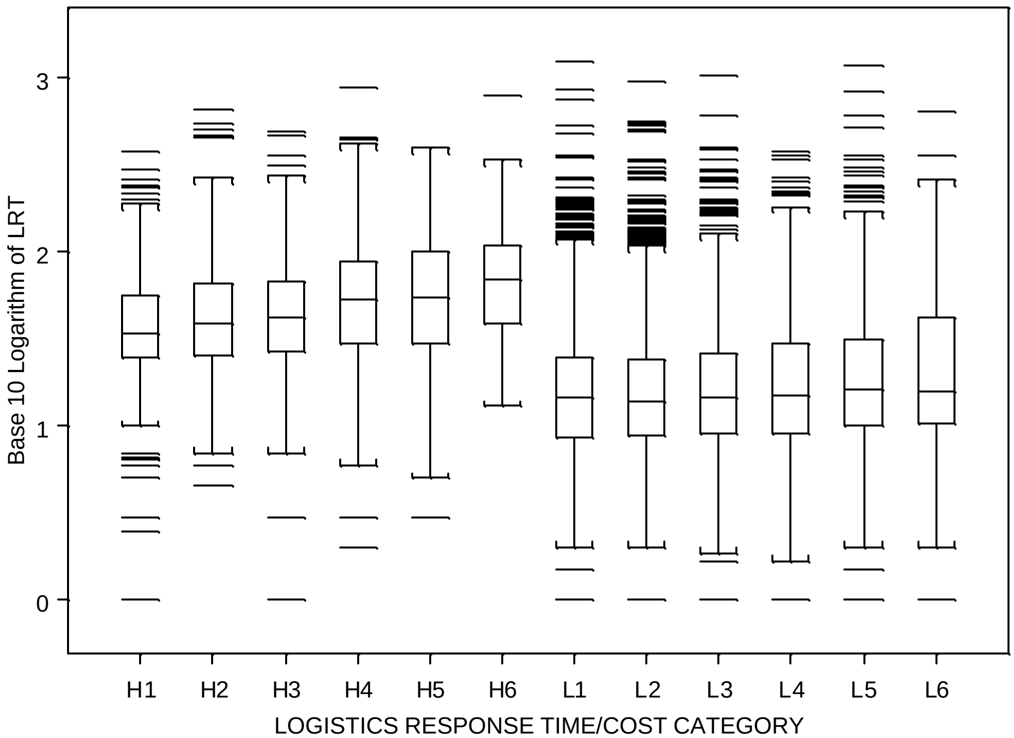

Figure 5.13: Boxplots of Average Base-10 Logarithm of Mean LRT by the Proposed LSSI Matrix LRT/Cost Categories. The "H" represents high LRT. The "L" indicates low LRT. The cost ranges from "1" (lowest) to "6" (highest).

Figure 5.14 shows the boxplots of base-10 logarithm of mean LRT by the proposed LSSI matrix LRT/Demand category. It is apparent that base-10 logarithm of LRT decreases as demand increases across both High and Low LRT demand categories. Comparing Figures 5.13 and 5.14, the median base-10 logarithm of mean LRT increases as cost increases. Conversely, base-10 logarithm of mean LRT decreases as demand increases.

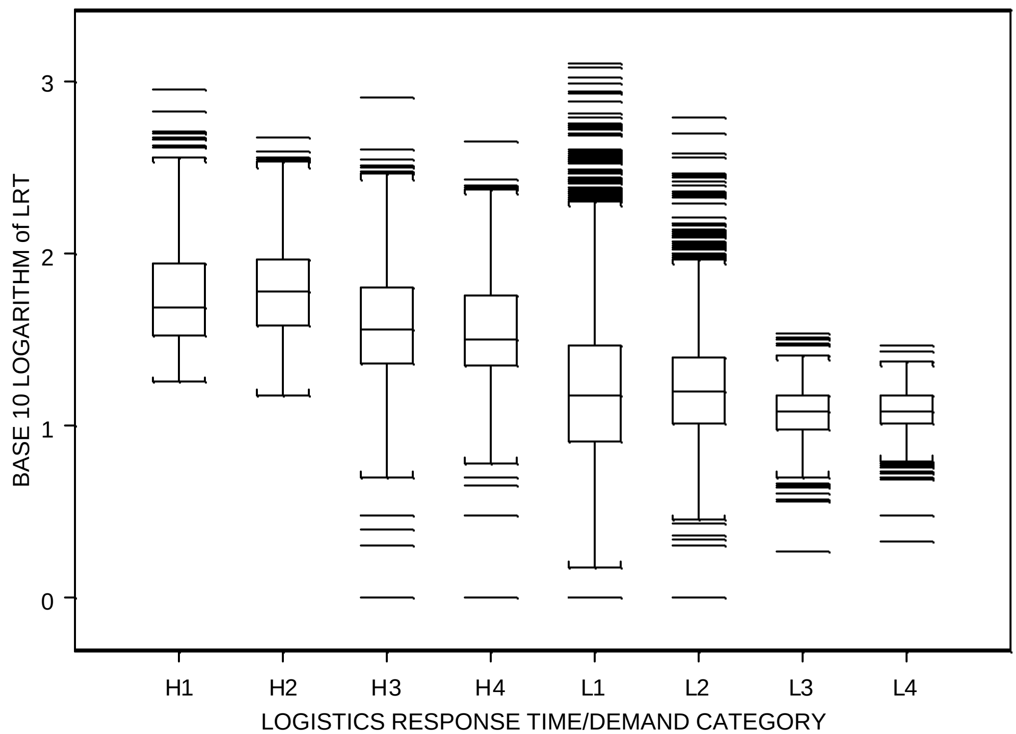

Figure 5.14: Boxplots of Average Base-10 Logarithm of Mean LRT by the Proposed LSSI Matrix LRT/Demand Categories. The "H" represents high LRT. The "L" indicates low LRT. The "1" and "2" indicate low and high demand respectively for non-focus items. The "3" and "4" indicate low and high demand respectively for focus items.

It is also apparent in Figure 5.13 that there are a number of items with high LRT across all LRT/Cost categories. One explanation of this occurring is that these NIINs are those that have an indeterminate mean LRT based on the ANOVA model and by the fact the mean LRT could have been calculated with only one observation. In addition, these items were placed either in the High LRT category if the NIIN was in the focus pool or in the Low LRT category if the NIIN was in the non-focus pool. A similar situation exists in Figure 5.14 with most prominent outliers in the "L1" and "L2" LRT/Demand categories.

There are over 3,800 non-focus pool NIINs with indeterminate LRT classifications because of small sample sizes or inconclusive data. However, these items

had high average LRTs based on their data. They are classified in the low LRT category due to their non-focus pool status. The median LRT for these NIINs is 19.2 days.

The same phenomenon occurs within the High LRT category but to a much lesser extent. There are 507 focus pool NIINs with indeterminate LRT classifications. Since the NIINs are focus pool items, they are classified with high LRT even though the mean LRT for the NIIN may be below the Navy's goal as in the case for several items.

In an attempt to improve this situation, the mean LRT of these "indeterminate" classifications can be scrutinized and the item added to the appropriate LRT category in the LSSI matrix.

F. IMPACTS OF PROPOSED SEGMENTATION

Two impacts are discussed about the new segmentation. First, the workload of NAVICP can be adjusted to bring non-focus pool items with High LRT and low SMA into a more visible status to management. Management can remove an equal amount or more of those focus pool items with Low LRT and high SMA.

Second, both the old and proposed LSSI matrices are run through the CARES application, discussed in Chapter IV. The two outputs are compared with particular emphasis on safety levels, SMA projections, and shortage costs. The workload impact and CARES output are discussed in the following sections.

1. Workload Impact. NAVICP can remove items from the Low LRT category focus pool items (columns 3 and 4 within the Low LRT category in Table 5.4) with high SMAs and replace them with the same number of items from the High LRT category non-focus pool (columns 1 and 2 within the High LRT category in Table 5.4) with low SMA, which ultimately leads to more efficient management of NIINs.

There are a total of 980 items classified with high LRT that are non-focus pool items. Of these, 273 have SMAs lower than 75 percent. The average SMA for these 273 items is 68.2 percent. If intense management attention is employed and an unlimited budget is available, these items can improve their performance to approximately 85 percent with an investment of $16.5 million. NAVICP can pick any number of non-focus pool items in the High LRT group with the lowest SMAs and add them to the focus pool for closer management review in an attempt to improve performance.

There are 738 focus pool items classified with low LRT. Of these, 395 have SMAs higher than 85 percent. These 395 NIINs have an average SMA of 92.3 percent. These items are meeting the SMA and mean LRT goals and can be removed from the focus pool. Resources in the amount of $5.95 million can be reallocated to those items not achieving SMA goals without adversely affecting their own SMAs.

2. Computation and Research Evaluation System (CARES) Output Comparison. This section discusses the comparison of the safety level investment and the projected SMA as well as the shortage costs of the 7,902 items run through CARES in the FY 2002 LSSI matrix and in the proposed LSSI matrix. The shortage costs of the proposed LSSI matrix cells are calculated using the process described in Ackart (2001). The constraints used for each CARES run are the same, overall SMA must be 85 percent and each cell's average SMA must fall between 70 and 90 percent. The comparison reveals that over half of the items do not change safety level or projected SMA.

Of the 7,902 NIINs, 1,270 or 16.1 percent experience a decrease in safety level investment. However, 2,087 experience an increase in safety level. The overall safety level investment for the FY 2002 LSSI matrix is $831.8 million. The proposed LSSI matrix has an overall safety level investment of $846.7 million, an increase of $14.9 million dollars. This results in a two percent increase in the safety level of the FY 2002 LSSI matrix. Appendix E contains the breakdown of the CARES output for the two LSSI matrices.

Comparing the SMA reveals just the opposite. Overall SMA increases from 85 percent for the existing LSSI matrix to 85.6 percent for the proposed LSSI matrix. There are 2,103 items that experience an increase in SMA to the 1,283 items that experience a decrease. The overall increase in SMA can be attributed to the change in shortage costs for some of the items, which increases the safety levels.

An analysis of shortage costs reveals that over half of the items experience an increase in shortage costs of $275 or more. This increase in shortage cost has a direct effect on safety levels. On the other hand, 40 percent have a decrease in shortage costs.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The segmentation of items by similar characteristics can be accomplished with the use of LRT. This segmentation by the modified weighted cost categories, the existing demand categories, and the new LRT categories will allow item managers to monitor items with higher LRTs more carefully. It may improve overall SMA with a small addition of safety level investment for some NIINs by placing those with High LRTs and low SMA in management "focus" that are not already in the focus pool. In contrast, less management attention is needed for those Low LRT, high SMA focus pool items. This proposed classification of High or Low LRT allows NAVICP to select the items to be managed in and out of management "focus" based on workload and the needs of the end-users. However, as this research shows, issue type, priority, requisition type and service designator can explain a significant percentage of variability in mean LRT of Naval aviation repairables. The ANOVA models described in this thesis can be utilized on a periodic basis to identify those non-focus pool NIINs experiencing High LRT and low SMA as candidates for higher management attention as well as those focus pool items experiencing Low LRT and high SMA as candidates for lower management attention.

B. RECOMMENDATIONS

This thesis recommends that the segmentation of Naval aviation repairable items include Logistics Response Time (LRT) as a criterion. Based on the analysis of 7,902 NIINs, these NIINs can be segmented using cost, demand and LRT. Using the model developed in this thesis, NAVICP management can identify those non-focus pool NIINs with High LRT and low SMA. These NIINs can then be moved into the "focused" category. In addition, those focus pool items with high SMA and Low LRT can be removed from close management attention. The use of this model periodically allows NAVICP management to shift their attention to those NIINs performing below established SMA and LRT goals.

In addition to using LRT as a segmentation criterion, there are several other recommendations to continue research in this manner. One research path that could be

investigated further is different segregation criterion. Local routing code, direct vendor delivery (DVD) contracts versus non-DVD contracts, and organic Navy depot versus commercial depot repair could be used to segregate items into segments for management of safety levels.

Shortage cost derivation is also a topic that could improve inventory management. A new automated system that computes shortage costs for each individual item ensures that each item stands alone in the levels setting programs in UICP. The LSSI shortage cost for each NIIN within a cell potentially underestimates the RISK for some items and overstates the RISK for others, which leads to higher safety levels for the former case and lower safety levels for the latter case. If each item has its own shortage cost, the safety level computations are more accurate.

Another recommendation is to encourage NAVICP to partner continuously with Defense Logistics Agency (DLA) and Naval Transportation Command (NAVTRANS) and other organizations to improve LRT. The partnering can ensure all segments of LRT are being measure accurately and are saved in the proper format. The local stock point or T-Shed receipt date can be used to more precisely measure the performance of transportation system. Monitoring this date in conjunction with ships' underway schedules can give NAVICP a true indication of how long it takes the item to get to the customer. How much does this process add to LRT? This obviously would not apply to shore activities.

One final aspect of LRT that can be studied is the shipboard receipt process. If this procedure can be improved, the customer receipt date can be captured on the actual date the material arrived on board. At the time this thesis was written, the date recorded in the UICP is the receipt date posted in the ship's supply system. This could be days after it made it on board.

APPENDIX A: DETAILED DATA FIELDS

Table A.1 lists the data fields in the Logistics Metrics Analysis Reporting System/Customer Wait Time (LMARS/CWT) data base provided by NAVICP. The actual database is maintained by DAASC.

Table A.2 lists the data fields in the Master Data File (MDF), which is managed by NAVICP.

Data Field	Data Type	Definition
National Item Identification Number NIIN	Character (9)	Unique, nine-digit code that identifies each repairable item managed by the NAVICP sites.
Document Number DOCNR	Character (14)	A code that uniquely identifies each receipt. The service designator, UIC and requisition date are located here.
ICP Receipt Date ICP.RCPT.DATE	Date in YYYY-MM-DD format (10)	The date the NAVICP received the requisition in the UICP system.
Material Release Order Date MRO.DATE	Date in YYYY-MM-DD format (10)	The date the NAVICP took positive supply action on the requisition.
Shipping Date SHIP.DATE	Date in YYYY-MM-DD format (10)	The date the material was shipped to the customer.
Customer Receipt Date CUST.RCPT.DATE	Date in YYYY-MM-DD format (10)	The date the customer receipted the item in its automated supply system.
PRIORITY	Numeric (2)	Urgency of the requirement
Local Routing Code LRC	Character (3)	Identifies which Weapon System Team within the NAVICP manages the NIIN.
Modified Total Pipeline Time (TPT) MODIFIED.TPT	Numeric	Time in days from ICP Receipt date to Customer Receipt Date.
Total Pipeline Time (TPT)	Numeric	Time in days from Requisition Date to Cust Rcpt Date.
Inventory Control Point Response Time ICPRT	Numeric	Time in days from ICP Receipt Date to MRO Date.
Project Code (PROJ)	Character (3)	Describes the end use of the material.
Issuing Depot ISSUING.DEPOT	Character (3)	Routing Identifier of stock point issuing material to the end-user.
ISSUE.TYPE	Character (1)	Identifies type of issue, “A” for immediate, “C” for backorder.
Mode of Shipment SHIP.MODE	Character (1)	Identifies how the material was shipped.
Requisition Type REQN.TYPE	Character (1), either “D” or “S”	Identifies the type of requirement, “D” is a direct turn over requirement, “S” is a stock requirement.

Table A.1: Logistics Metrics Analysis Reporting System/Customer Wait Time (LMARS/CWT) Data Description.

Data Field	Data Type	Definition
National Item Identification Number NIIN	Character (9)	Unique, nine-digit code that identifies each repairable item managed by the NAVICP sites.
Federal Supply Class FSC	Character (4)	Unique four-digit code that identifies the federal material category the component would generally be classified under.
Levels Settings Segment Indicators LSSI	Character (2)	A two-digit code identifying which shortage cost will be used in levels setting models with in the UICP.
Local Routing Code LRC	Charter (3)	Identifies which Weapon System Team within the NAVICP manages the NIIN.
Standard Price DEN B053	Numeric	The cost of a new component or the cost charged to an end-user for a component with no available carcass for turn-in.
Replacement Price DEN B055	Numeric	The cost of the component assuming the carcass of the failed component is available for repair and submitted into repair.
Repair Price DEN B055A	Numeric	The cost to repair a component.
Item Mission Essentiality Code IMEC	Numeric (1)	A measure of the importance of an item to the Navy's mission.
Family Status FAM	Character (1), "H" for head, "B" for bachelor	Tells whether there are NIINs related to this NIIN or if it is one of a kind and purpose.
Positive Safety Level Value PSLD	Numeric	Value of safety level at Standard Price.

Table A.2: Master Data File (MDF) Data Description.

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APPENDIX B: DETAILED MANAGEMENT DATA OF TEST SET ITEMS

Table B.1 provides the following management data of the test set NIINs:

National Item Identification Number (NIIN)

Nomenclature

Old Levels Setting Segment Indicator (LSSI)

Standard Price

Positive Safety Level Value.

Table B.2 provides the following management data of the test set NIINs:

NIIN

Nomenclature

Annual Requisition Frequency

Supply Material Availability (SMA)

Local Routing Code (LRC)

Item Military Essentiality Code (IMEC)

NIIN	NOMENCLATURE	LSSI	Standard Price	PSLV
000508618	CONTROL, INTERCOMM SET	A4	$1,690	$7,258
000823357	CONE, EXHAUST, TURBINE ENGINE	B3	$3,750	$37,967
001022425	CONTROL, RADIO SET	A4	$16,800	$56,342
004347642	ROTOR COMPRESSOR AIRCRAFT GAS	J3	$55,010	$257,722
006273721	CIRCUIT CARD ASSY	C4	$5,120	$184,835
009156880	CONTROL ASSY, HEATER	E3	$8,460	$9,101
010221737	AMPLIFIER, TRIGGER, PULSE	K4	$274,220	$782,830
010405605	HARNESS ASSY	C3	$22,490	$91,747
010639553	CONVERTOR, ANALOG TO DIGITAL	I4	$37,990	$203,930
010864200	COMPUTER, ROLL	F4	$85,880	$13,230
011251001	GEARSHIFT, SPUR	F3	$22,160	$60,785
011258013	CANOPY, MOVABLE	J3	$79,980	$330,589
011506719	INDICATOR, DIGITAL DISPLAY	J4	$118,710	$281,369
011520445	SOLENOID VALVE, SPECIAL	B3	$6,950	$55,807
011589679	BLADE ROTARY WING	J3	$97,010	$2,195,006
011757165	ELECTRONIC COMPONENTS ASSY	I4	$45,650	$1,569,086
011861399	MOTOR ROLL DRIVE	C3	$3,920	$84,830
011872225	CARD, PLUG-IN, PROGRAMMER	D3	$6,760	$29,167
011932159	SERVOCYLINDER	I3	$153,720	$647,653
012053007	ENCODER ASSY	J4	$624,700	$180,445
012132334	RECEIVER, COUNTERMEASURE	J4	$316,370	$110,730
012328815	HOOK, SUBASSY, ARRESTING	H4	$50,370	$5,119,196
012329009	TURBINE, AIRCRAFT COOLING	H4	$37,580	$781,523
012475025	RECEIVER, EXCITER	J3	$686,360	$10,851,283
012755697	INDICATOR, DIGITAL DISPLAY	J4	$50,700	$130,847
012798219	MONITOR, COLORGRAPHIC	F4	$13,530	$61,690
012960634	COMPRESSOR, ROTARY	I4	$55,380	$1,331,501
012963813	VALVE, TEMP DATUM	E3	$15,400	$222,930
013028637	SWITCHING UNIT, POWER TRANSFER	J4	$93,300	$47,793
013042152	CONVERTER UNIT, GENERATOR	I4	$127,200	$2,381,966
013177949	CIRCUIT CARD ASSY	B4	$6,340	$27,398
013206599	AMPLIFIER, CTROL, INTERCOM	G4	$105,490	$260,529
013346839	CIRCUIT CARD ASSY	C4	$7,010	$79,749
013446057	TURBINE ROTOR, TURBINE ENGINE	J3	$119,710	$54,540
013857177	CONTROL GENERATOR	I3	$54,150	$268,075
013864242	MANIFOLD ASSY, HYDRAULIC	F3	$7,840	$71,239
014480776	POWER SUPPLY	G3	$15,900	$1,369
014555215	BLADE ROTARY WING	I3	$135,550	$1,733,983
014555217	BLADE ROTARY WING	J3	$134,960	$1,334,113
997636187	NA	I3	$64,020	$59,327

Table B.1: Detailed Management Data for the Test Set Items.

NIIN	NOMEN	Reqn Freq (Ann)	Projected SMA	LRC	IMEC
000508618	CONTROL, INTERCOMM SET	17	0.95	QML	5
000823357	CONE, EXHAUST, TURBINE ENGINE	39	0.96	SJ3	5
001022425	CONTROL, RADIO SET	17	0.95	PJ5	4
004347642	ROTOR COMPRESSOR AIRCRAFT GAS	111	0.53	SX1	5
006273721	CIRCUIT CARD ASSY	152	0.97	QB5	4
009156880	CONTROL ASSY, HEATER	54	0.69	XTY	4
010221737	AMPLIFIER, TRIGGER, PULSE	17	0.85	PKT	4
010405605	HARNESS ASSY	50	0.81	VHG	2
010639553	CONVERTOR, ANALOG TO DIGITAL	66	0.72	HZB	4
010864200	COMPUTER, ROLL	16	0.81	PLC	5
011251001	GEARSHIFT, SPUR	61	0.77	SF3	5
011258013	CANOPY, MOVABLE	54	0.68	AFG	4
011506719	INDICATOR, DIGITAL DISPLAY	29	0.7	ACC	4
011520445	SOLENOID VALVE, SPECIAL	63	0.94	AJB	2
011589679	BLADE ROTARY WING	246	0.72	YXH	5
011757165	ELECTRONIC COMPONENTS ASSY	55	1	ACA	5
011861399	MOTOR ROLL DRIVE	167	0.95	ACE	5
011872225	CARD, PLUG-IN, PROGRAMMER	49	0.93	UYL	4
011932159	SERVOCYLINDER	69	0.61	HPB	5
012053007	ENCODER ASSY	5	0.69	DMF	4
012132334	RECEIVER, COUNTERMEASURE	6	0.69	DMF	4
012328815	HOOK, SUBASSY, ARRESTING	703	0.93	AGD	5
012329009	TURBINE, AIRCRAFT COOLING	222	0.73	AJA	4
012475025	RECEIVER, EXCITER	101	0.66	ACA	5
012755697	INDICATOR, DIGITAL DISPLAY	27	0.63	HX1	5
012798219	MONITOR, COLORGRAPHIC	47	0.84	UYL	4
012960634	COMPRESSOR, ROTARY	398	0.57	LDD	5
012963813	VALVE, TEMP DATUM	233	0.72	SX1	5
013028637	SWITCHING UNIT, POWER TRANSFER	7	0.73	E1A	5
013042152	CONVERTER UNIT, GENERATOR	261	0.72	AKC	4
013177949	CIRCUIT CARD ASSY	34	0.96	AEA	2
013206599	AMPLIFIER, CTROL, INTERCOM	55	0.7	ADF	4
013346839	CIRCUIT CARD ASSY	94	0.85	QB5	0
013446057	TURBINE ROTOR, TURBINE ENGINE	69	0.9	SE2	5
013857177	CONTROL GENERATOR	37	0.67	C3E	0
013864242	MANIFOLD ASSY, HYDRAULIC	73	0.76	AJB	0
014480776	POWER SUPPLY	19	0.69	ADB	0
014555215	BLADE ROTARY WING	76	0.84	VM6	0
014555217	BLADE ROTARY WING	89	0.73	VM6	0
997636187	NA	54	0.82	QGC	0

Table B.2: Additional Detailed Management Data for the Test Set Items.

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APPENDIX C: SOFTWARE USED FOR ANALYSIS

The following S-Plus functions were used in performing the LRT data analysis. This function takes each item in a NIIN list and performs ANOVA on an item-by-item basis. It is set up to run ANOVAs with each predictor variable either individually, additively or interactively up to two-way. The output gives the modified TPT variance before and after the ANOVA. From this information, confidence intervals can be computed.

```
CleanLRT
function(nlist)
{
###########################################################################
# The CleanLRT function's input is a list of NIINs. The function matches the each NIIN
# with its requisitions in the LMARS/CWT database and writes the sample size to an
# output file. It then computes the levels of the four factors contained in the data for
# each NIIN and writes it to the output file. Based on the factors that can be fitted in the
# ANOVA model, the CleanLRT function selects an ANOVA model to be fitted with
# each NIIN's requisitions. If there are the same combination of each factor or if there is
# only one level of all factors, the variance does not change and no ANOVA model can
# be fitted. If the ANOVA model fits, the variances of logarithm of LRT before and
# after the ANOVA are written to the output file. The degrees of freedom and the grand
# mean of logarithm of LRT are recorded in the output file.
###########################################################################
	m <- length(nlist)
	mout <- floor(m/100 + 0.5)
	####################################################################
	# Constructs the data frame containing variance before ANOVA,
	# variance after ANOVA, number of service designator levels,
	# number of IPG levels, number of requisition type levels, and number
	# of issue type levels, the degrees of freedom, the same size and the grand mean
	# of the LRTs for that NIIN across all requisitions.
	####################################################################
	Varmat <- matrix(0, m, 9)
	dimnames(Varmat) <- list(NULL, c("V.Before", "V.After", "Use.SVC",
		"Use.Prty", "Use.ReqType", "Use.Issue", "Deg.Fr", "N",
		"GRAND.MEAN"))
	tmatch0 <- match(FY01new[, "DOCNR"], Y01[, "DOCNR"])
	#####################################################################
	# Established the models that can be used to fit the model for each NIIN.
	#####################################################################
```

```
flist0 <- list(LRT ~ REQNTYPE, LRT ~ IPG, LRT ~ (IPG + REQNTYPE)^2,
        LRT ~ SVC.DES, LRT ~ (SVC.DES + REQNTYPE)^2, LRT ~
        (SVC.DES + IPG)^2, LRT ~ (SVC.DES + IPG + REQNTYPE)^2)
flist1 <- list(LRT ~ REQNTYPE + ISSUE, LRT ~ IPG + ISSUE, LRT ~ (IPG +
        REQNTYPE + ISSUE)^2, LRT ~ SVC.DES + ISSUE, LRT ~ (SVC,DES
        + REQNTYPE + ISSUE)^2, LRT ~ (SVC.DES + IPG + ISSUE)^2, LRT
        ~ (SVC.DES + PRIOR + REQNTYPE + ISSUE)^2)
ihi <- 0
j <- 0
for(kk in 1:mout) {
        ilo <- ihi + 1
        ihi <- min(c(ihi + 100, m))
        mdo <- ihi - ilo + 1
        tt <- !is.na(Y01[tmatch0, "MODIFIED.LRT"] + match(Y01[
                tmatch0, "NIIN"], nlist[ilo:ihi])) & cust.yr[tmatch0
                ] > 1000 & mro.yr[tmatch0] > 1000
        tt <- tt & FY01new[, "REQN.TYPE"] != "O"
        tmatch <- tmatch0[tt]
        n <- sum(tt)
        ###########################################################
        #  Constructs the data frame containing the LRT, NIIN, service
        #  designator, IPG, requisition type and issue type for all requisitions
        #  having one of the NIINs in the input list.
        ###########################################################
        Yanov <- data.frame(log(Y01[tmatch, "MODIFIED.TPT"]), Y01[
                tmatch, "NIIN"], svcdeg[tmatch], prior.grp[tmatch],
                FY01new[tt, "REQN.TYPE"], FY01new[tt, "ISSUE.TYPE"])
        names(Yanov) <- c("Y", "NIIN", "SVC", "PRIOR", "REQTYPE",
                "ISSUE")
        dfvec <- numeric(7)
        for(jj in 1:mdo) {
                j <- j + 1
                tt <- Yanov[, 2] == nlist[j]
                ntt <- sum(tt)
                Varmat[j, 8] <- ntt
                moduse <- rep(T, 7)
                ###########################################################
                #Determines number of levels for each factor
                ###########################################################
                nis <- length(unique(Yanov[tt, 6]))
                nsv <- length(unique(Yanov[tt, 3]))
                if(nsv == 1)
                        moduse[c(4, 5, 6, 7)] <- F
                npr <- length(unique(Yanov[tt, 4]))
                if(npr == 1)
                        moduse[c(2, 3, 6, 7)] <- F
```

```
				nrq <- length(unique(Yanov[tt, 5]))
				if(nrq == 1)
					moduse[c(1, 3, 5, 7)] <- F
				#####################################################
				#Calculates the degrees of freedom for the model fit on each NIIN
				#####################################################
				dfvec[c(2, 1, 4)] <- ntt - c(npr, nrq, nsv) * nis
				dfvec[3] <- ntt - npr * nrq * nis
				dfvec[6] <- ntt - npr * nsv * nis
				dfvec[5] <- ntt - nrq * nsv * nis
				dfvec[7] <- ntt - (npr * nrq - npr * nsv - nrq * nsv +
					npr + nrq + nsv) * nis - 1
				kdf <- which(moduse & (dfvec > 0))
				ncode <- length(kdf)
				if(ncode > 0)
					ncode <- kdf[ncode]
				Varmat[j, 3:6] <- c(nsv, npr, nrq, nis)
				Varmat[j, 1] <- var(Yanov[tt, 1])
				Varmat[j, 9] <- mean(Yanov[tt, 1])
				if(ncode > 0)
					if(nis == 1)
					  alist <- aov(flist0[[ncode]], data = Yanov[
					    tt,  ])
					else alist <- aov(flist1[[ncode]], data =
					    Yanov[tt,  ])
				if(ncode == 0) {
					Varmat[j, 2] <- Varmat[j, 1]
					Varmat[j, 7] <- Varmat[j, 8] - 1
				}
				else {
					Varmat[j, 2] <- sum(alist$residuals^2)/alist$
					  df.residual
					Varmat[j, 7] <- alist$df.residual
				}
				cat("Finished NIIN ", j, "\n")
			}
		}
		return(list(Y = Yanov, V = Varmat))
}
```

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APPENDIX D: ADDITIONAL RESULTS OF DATA ANALYSIS

All tables in this appendix show classifications for the FY 2005 Logistics Response Time goal of 14 days for all test set NIINs.

Table D.1 gives the detailed output of the ANOVA models for the test set items. Output includes the variance of natural log transformation of mean LRT before and after ANOVA, the number of levels for each factor used in the models (issue type, requisition type, issue priority group and service designator), the degrees of freedom, the sample size and the grand mean of natural log transformation of mean LRT.

Table D.2 shows the initial classification of the LRT, the final classification the proposed LSSI based on the FY 2005 goal of 14 days, and the 90 percent upper and lower confidence bounds.

Table D.3 shows the raw classification results of the entire set of 7,902 items; it lists whether the items are classified as High LRT, Low LRT, or Indeterminate.

Table D.4 shows the final classifications of all 7,902 items; it lists whether the item was High or Low based on the criteria discussed in Chapter V.

NIIN	Variance Before	Variance After	# of Svc Des	# of Priority	# of Reqn	# of Issue	Degree Freed	Sample Size	Grand Mean
000508618	1.11	0.82	2	2	2	1	9	12	2.73
000823357	1.24	0.17	2	2	2	1	53	57	1.98
001022425	0.71	0.59	3	2	2	2	4	8	2.36
004347642	0.54	0.45	3	2	2	2	65	70	3.56
006273721	0.49	0.23	3	2	2	2	115	123	2.12
009156880	1.07	0.64	3	2	2	1	18	23	2.37
010221737	1.16	0.40	3	2	2	1	7	11	1.52
010405605	2.43	0.81	3	3	2	2	33	44	2.70
010639553	0.60	0.55	3	2	2	1	39	45	2.31
010864200	1.54	0.14	2	2	2	2	7	11	2.53
011251001	1.23	0.70	3	2	2	2	19	29	3.59
011258013	1.03	0.93	3	2	1	2	26	32	4.26
011506719	0.77	0.67	2	2	2	2	18	22	3.06
011520445	0.74	0.49	3	2	2	2	74	86	2.69
011589679	1.73	0.65	3	2	2	3	142	152	2.11
011757165	2.71	0.37	3	2	2	2	24	33	2.95
011861399	0.66	0.58	3	2	2	1	108	117	1.86
011872225	1.52	0.17	3	2	2	3	29	38	2.59
011932159	0.51	0.43	3	2	2	1	40	45	1.82
012053007	0.57	0.02	2	2	2	2	5	9	2.57
012132334	0.25	0.00	2	2	2	2	4	9	3.07
012328815	1.01	0.72	3	3	2	2	428	443	4.11
012329009	1.11	0.62	3	3	2	2	132	145	2.70
012475025	2.13	0.65	3	2	2	2	13	21	3.97
012755697	1.24	0.47	3	2	2	2	15	20	3.89
012798219	0.17	0.21	3	2	2	1	5	9	3.17
012960634	0.45	0.34	2	2	2	2	277	287	3.02
012963813	0.79	0.59	2	2	2	2	104	110	1.74
013028637	1.35	0.21	3	2	1	1	10	14	1.92
013042152	1.84	0.79	3	2	2	2	64	75	3.65
013177949	0.92	0.70	3	2	2	2	23	35	2.99
013206599	2.14	0.81	3	2	2	2	14	25	3.52
013346839	0.67	0.44	3	2	2	1	105	111	2.16
013446057	1.64	1.27	3	2	2	1	19	24	2.66
013857177	1.70	0.62	3	2	2	2	21	32	2.90
013864242	0.38	0.34	2	2	2	2	2	5	2.74
014480776	1.49	0.76	3	2	2	2	15	26	2.84
014555215	2.07	0.00	2	1	1	2	2	5	4.14
014555217	1.31	0.51	3	2	1	2	9	15	2.28
997636187	1.08	0.45	3	2	2	2	85	97	1.37

Table D.1: Analysis of Variance Results for Test Set Items.

NIIN	OLD LSSI	NEW LSSI	Raw LRT Class	Final LRT Class	Lower Conf Int	Upper Conf Int
000508618	A4	H4.1	Indeterminate	High	9.55	24.82
000823357	B3	L3.1	Low	Low	6.59	7.92
001022425	A4	H4.1	Indeterminate	High	5.92	18.87
004347642	J3	H3.5	High	High	30.70	40.05
006273721	C4	L4.2	Low	Low	7.79	9.00
009156880	E3	H3.3	Indeterminate	High	8.04	14.35
010221737	K4	L4.6	Low	Low	3.19	6.54
010405605	C3	H3.2	Indeterminate	High	11.79	18.64
010639553	I4	L4.5	Low	Low	8.36	12.15
010864200	F4	H4.3	Indeterminate	High	10.15	15.65
011251001	F3	H3.3	High	High	27.81	47.66
011258013	J3	H3.5	High	High	52.73	94.47
011506719	J4	H4.5	High	High	15.71	28.78
011520445	B3	H3.1	Indeterminate	High	12.97	16.66
011589679	J3	L3.5	Low	Low	7.43	9.23
011757165	I4	H4.5	High	High	15.88	22.78
011861399	C3	L3.2	Low	Low	5.71	7.21
011872225	D3	H3.2	Indeterminate	High	11.85	14.86
011932159	I3	L3.5	Low	Low	5.25	7.29
012053007	J4	H4.5	Indeterminate	High	11.83	14.48
012132334	J4	H4.5	High	High	20.68	22.55
012328815	H4	H4.4	High	High	57.01	65.14
012329009	H4	H4.4	Indeterminate	High	13.32	16.55
012475025	J3	H3.5	High	High	38.82	72.34
012755697	J4	H4.5	High	High	37.27	63.75
012798219	F4	H4.3	High	High	17.44	32.30
012960634	I4	H4.5	High	High	19.45	21.79
012963813	E3	L3.3	Low	Low	5.07	6.47
013028637	J4	L4.5	Low	Low	5.49	8.52
013042152	I4	H4.5	High	High	32.36	45.62
013177949	B4	H4.1	High	High	15.65	25.42
013206599	G4	H4.4	High	High	24.69	46.46
013346839	C4	L4.2	Low	Low	7.80	9.62
013446057	J3	H3.5	Indeterminate	High	9.58	21.21
013857177	I3	H3.5	High	High	14.30	23.06
013864242	F3	H3.3	Indeterminate	High	7.25	33.41
014480776	G3	H3.4	Indeterminate	High	12.75	23.19
014555215	I3	H3.5	High	High	57.94	68.61
014555217	J3	L3.5	Low	Low	6.99	13.77
997636187	I3	L3.5	Low	Low	3.51	4.40

Table D.2: Data Analysis Output for the Test Set Items.

Model	High	Low	Indeterminate	NA
AOV 14	1659	1875	2971	1412

Table D.3: Raw classification of NIIN Mean LRT. Each cell could be either High, Low, Indeterminate or NA. AOV 14 is the ANOVA results for the FY 2005 goal of 14 days. All 7,902 NIINs are classified.

Model	High	Low
AOV 14	2164	5749

Table D.4: Final Classification of NIIN Mean LRT. Each NIIN is either High or Low. All 7,902 NIINs are classified.

APPENDIX E: COMPUTATION AND RESEARCH EVALUATION SYSTEM (CARES) OUTPUT

Appendix E lists the CARES outputs for the FY 2002 Levels Setting Segment Indicator matrix, Table E.1, and the proposed Levels Setting Segment Indicator matrix, Table E.2, for all 7,902 NIINs. Both outputs include the following data for each cell in the Levels Setting Segment Indicator**:**

1. Levels Setting Segment Indicator: Indicates which cost/demand category the item falls in FY 2002 (Table E.1) and indicates which LRT/demand/cost category the items falls in the proposed LSSI (Table E.2).
2. Safety Level in $millions: Cumulative sum of safety level for all items within the LSSI cell.
3. Value of Annual Demand in $millions: Cumulative sum of the forecasted demand multiplied by the standard price of all items within the LSSI cell.
4. Projected Supply Material Availability: Percentage of time material is available for release when a requisition is received at NAVICP averaged over all items within the LSSI cell.
5. Shortage Cost (Lambda): Cost used in computing RISK in the UICP models for all items within the cell.
6. Number of Items: The number of items in the LSSI cell.
7. Frequency of Requisitions: Anticipated number of annual requisitions.

Table E.1: CARES Output for 7,902 NIINs Using FY 2002 LSSI Matrix.

LSSI	SL $M	VAD $M	SMA	LAMBDA	# ITEMS	FREQ
A1	1.18	11.01	90.80	810	592	2685
B1	2.80	25.72	90.39	1550	759	3665
C1	5.27	46.73	90.86	2690	656	3318
D1	4.10	35.52	89.19	3500	524	2500
E1	2.24	47.83	84.45	2930	465	2353
F1	1.51	52.98	78.22	100	324	1809
G1	2.10	67.26	79.08	100	269	1357
H1	2.77	93.53	75.64	100	260	1429
I1	3.58	98.92	72.58	100	174	919
J1	4.83	84.50	70.31	16860	108	542
K1	7.65	128.86	70.21	23880	77	338
A2	1.52	14.59	90.46	692	189	3811
B2	4.20	40.33	89.99	1395	257	5243
C2	8.27	60.96	90.06	2300	271	5537
D2	9.43	63.56	89.75	3640	217	4509
E2	9.11	88.16	85.78	3692	203	4209
F2	3.31	105.22	73.50	100	129	2722
G2	4.08	129.93	69.98	3115	138	2900
H2	11.02	175.72	70.20	6980	129	2727
I2	26.06	317.13	69.04	11920	124	2640
J2	20.22	230.31	69.90	26200	67	1371
K2	39.53	368.41	69.60	61200	48	1059
A3	7.28	47.03	89.85	1510	109	38535
B3	7.76	62.05	89.88	1840	126	10323
C3	20.34	171.94	90.50	3555	185	22191
D3	17.32	111.04	89.79	5540	143	9741
E3	31.57	188.70	90.09	9310	130	9899
F3	39.83	281.01	87.17	11170	122	10752
G3	15.80	249.42	71.20	6100	78	5655
H3	38.85	500.44	69.89	11400	83	6732
I3	37.54	501.32	70.03	15380	88	6844
J3	63.99	754.24	69.75	33200	53	4341
K3	73.28	886.40	70.77	102400	39	2799
A4	2.31	23.42	89.91	1210	47	6254
B4	9.68	97.93	89.88	3075	84	11688
C4	17.65	138.67	89.87	4970	119	14010
D4	35.22	252.99	90.07	9120	109	13229
E4	26.91	196.93	89.42	10540	93	9321
F4	36.65	348.70	82.20	11270	79	8331
G4	19.47	206.78	76.86	8075	65	5232
H4	35.26	419.44	69.97	12980	67	6090
I4	49.56	439.96	69.90	28800	43	3986
J4	24.40	259.83	68.86	29000	30	1335

LSSI	SL $M	VAD $M	SMA	LAMBDA	# ITEMS	FREQ
K4	45.81	481.32	70.33	57140	30	1736
	Total	Total	Aver		Total	Total
	831.26	8906.74	85.01		7902	266667

Table E.2: CARES Output for 7,902 NIINs Using Proposed LSSI Matrix.

LSSI	SL $M	VAD $M	SMA	LAMBDA	# ITEMS	FREQ
H1.1	0.48	5.38	90.40	1170	154	899
H2.1	1.60	17.30	90.32	1270	100	2080
H3.1	4.51	62.32	90.44	700	145	31617
H4.1	5.06	53.81	89.93	2000	72	9100
H1.2	1.19	11.45	89.98	2640	145	905
H2.2	6.09	34.07	90.17	3040	104	2242
H3.2	20.60	152.32	90.20	4470	183	12816
H4.2	27.85	221.45	90.10	6800	116	13279
H1.3	2.26	15.88	90.30	6680	80	500
H2.3	4.56	84.09	80.29	3295	100	2156
H3.3	53.45	323.05	90.22	12720	152	12208
H4.3	42.14	290.08	90.01	15860	95	8554
H1.4	0.73	33.56	77.67	100	74	475
H2.4	4.27	92.68	69.70	4796	74	1622
H3.4	37.36	586.29	70.39	8410	114	8713
H4.4	41.28	490.83	72.35	11275	87	8097
H1.5	1.69	36.52	70.80	100	45	269
H2.5	17.68	212.75	70.27	17300	71	1521
H3.5	70.43	1043.47	70.92	20900	116	8844
H4.5	60.83	525.11	69.82	32150	54	3818
H1.6	1.32	16.53	70.32	39920	12	60
H2.6	19.35	200.14	70.39	67800	21	434
H3.6	59.62	742.85	70.38	105000	28	2018
H4.6	29.97	371.24	69.62	48620	22	1075
L1.1	3.34	31.35	90.18	1150	1197	5450
L2.1	3.76	37.62	89.83	1015	346	6974
L3.1	8.69	46.75	89.90	7000	90	17241
L4.1	4.52	67.55	85.29	1600	59	8842
L1.2	8.84	70.80	89.95	2965	1035	4913
L2.2	11.75	90.46	90.18	2890	384	7803
L3.2	16.58	130.66	90.01	3900	145	19116
L4.2	23.22	170.21	89.83	6840	112	13960
L1.3	6.16	84.93	85.26	4000	709	3662
L2.3	17.07	109.28	90.00	6320	232	4775
L3.3	26.81	146.65	90.95	13000	100	8442
L4.3	35.38	255.55	89.75	16740	77	9097
L1.4	4.15	127.23	77.24	100	455	2311
L2.4	10.25	212.97	69.86	4340	193	4005
L3.4	14.55	163.57	72.51	10050	47	3674
L4.4	13.34	135.39	76.12	10050	45	3224
L1.5	5.58	146.90	71.21	100	237	1191
L2.5	29.44	334.69	70.08	14470	120	2490
L3.5	20.64	212.08	69.89	28500	25	2342

LSSI	SL $M	VAD $M	SMA	LAMBDA	# ITEMS	FREQ
L4.5	14.56	174.68	69.84	23470	19	1504
L1.6	6.38	112.33	70.14	18550	65	277
L2.6	20.79	168.27	69.36	59100	27	625
L3.6	14.56	143.55	70.49	89000	11	781
L4.6	12.02	110.08	68.99	63040	8	661
	Total	Total	Aver		Total	Total
	846.70	8906.72	85.59		7902	266662

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